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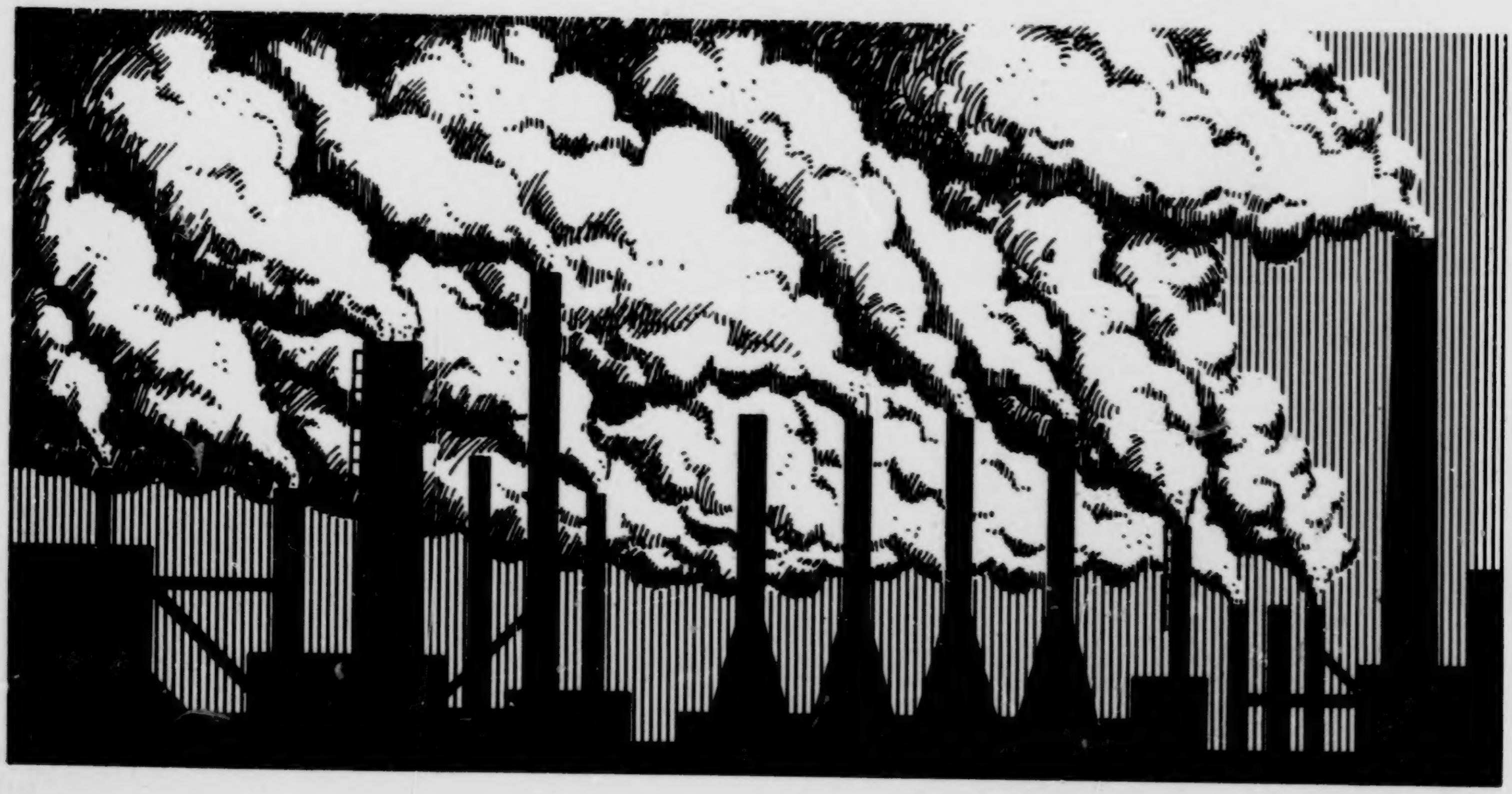

PARTICULATE POLLUTANT SYSTEM STUDY
VOLUME I - MASS EMISSIONS

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A program on particulate air pollution from stationary sources in the continental United States was conducted. The specific objective of the study was to identify, characterize, and, to the extent possible, quantify the particulate air pollution problem. Information was to be assembled and analyzed on the kind and magnitude of specific sources, and the status of current control practices. The resultant information was to be used to identify deficiencies in current knowledge regarding the nature of important particulate pollution sources, and to provide requisite handbook data for the design and application of control devices. The results of the study are presented in this report and in a separate handbook.

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PARTICULATE POLLUTANT SYSTEM STUDY

Volume I - Mass Emissions

1 May 1971

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Prepared for

Air Pollution Control Office
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411 West Chapel Hill Street
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PREFACE

This report was prepared for APCO under Contract No. CPA-22-69-104, which was monitored by Mr. Timothy Devitt and Mr. Don Felton.

The work was conducted in the Environmental Pollution Section of the Physical Sciences Division.

The report was written by Dr. A. E. Vandegrift, Project Director, and Dr. L. J. Shannon with the assistance of Mr. P. G. Gorman, Dr. E. W. Lawless, Mr. E. E. Sallee, and Miss M. Reichel.

Dr. Seymour Calvert and Mr. Paul L. Magill, consultants to MRI, made many valuable comments and contributions to this document. Dr. Larry Faith, Dr. Louis McCabe, and Dr. Frank Fowler also contributed to the program.

Approved for:

MIDWEST RESEARCH INSTITUTE

H. M. Hubbard, Director
Physical Sciences Division

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SUMMARY

A program on particulate air pollution from stationary sources in the continental United States was conducted at Midwest Research Institute under the sponsorship of the Air Pollution Control/EPA Office. This study is one of a series of programs sponsored by APCO to assess the national particulate pollution problem, and more importantly to advance the capability of control equipment for particulate emissions.

APCO/EPA and the federal government through APCO are placing emphasis on this specific area of pollution because of the numerous problems that can be created by particulate pollution. Particulate pollutants may exert adverse effects in the areas of human health, esthetics, and economics. Health problems include respiratory ailments, toxic reactions, and eye or skin irritations. Esthetic problems include soiling, decrease in visibility of the atmosphere, and odor. Economic effects include material damage, increased cleaning cost because of soiling, and general neighborhood deterioration. The contribution of a specific source to the overall problems in any of the above areas depends upon the rate of emission, the physical and chemical characteristics of the emissions and the environment surrounding the emission source.

The only feasible way of alleviating or averting the problems created by particulate pollution is to control the pollutant at its source. Control of particulate pollutants is facilitated by detailed knowledge of the sources and the properties of the effluents from these sources. The specific objective of the present study was to identify, characterize, and, to the extent possible, quantify the particulate air pollution problem. Information was to be assembled and analyzed on the kind and magnitude of specific sources, the characteristics of both particulate and carrier gas from specific sources, and the status of current control practices. The resultant information was to be used to identify deficiencies in current knowledge regarding the nature of important particulate pollution sources, and was to provide requisite handbook data for the design and application of control devices.

The program organization and principal results are highlighted in the following paragraphs.

Program Organization

The program was divided into five phases: (1) sources; (2) effluents; (3) controls; (4) future problems; and, (5) R&D plans. The two major tasks in Phase 1 were to identify all significant sources of particulate pollutants and to evaluate the most important sources. Phase 2 was directed to the characterization of the total effluent stream from important particulate sources. The determination of current particulate pollution control practices and the extent to which each of the important particulate emission sources is now controlled was conducted in Phase 3. Future problem particulate emission sources, determined by projecting production trends, control efficiency, and control equipment application trends, were identified in Phase 4. In Phase 5 research and development plans were formulated to fill in the knowledge gaps pinpointed during the study.

Presentation of Results

The results of the study are presented in two documents. The first document, Volume I, Mass Emissions, covers the results of Phases 1, 4 and 5 of the program. The second document, Volume III, Handbook of Emission Properties, presents the results of Phases 2 and 3. A bibliography, intended as a companion document, of all the information sources collected during the program was also prepared. The bibliography contains more than 3,000 references.

Information Acquisition

To obtain as much pertinent information as possible, a rapid literature survey was conducted to delineate information sources. This step permitted a general definition of the scope of the information acquisition process. The literature search included scientific abstracts, technical libraries, government literature, air pollution journals, and periodicals pertaining to specific industries. Information was also obtained by personal contacts with government agencies dealing with air pollution problems, industrial organizations which are sources of particulate pollutants, industrial associations, control equipment manufacturers, stack sampling organizations, and key researchers in the field.

All information that was received in the form of a written article or report was coded, key worded, and stored for retrieval on a computer. Complete details of the information acquisition activity and the computer information retrieval system are presented in Sections 2 and 3, pages 33 to 47.

Important Sources

To determine which sources were important, a comprehensive list of all possible significant sources was prepared. This list is presented in Appendix B. From the list of significant sources, a ranking of the most important sources by total tonnage emitted was developed by calculating total emissions using emission factor techniques and other calculation methods. Figure S-1 illustrates the distribution of emissions by industry. The left-hand column in Table S-1 presents the actual emission quantities.

The emission factor method of calculation is based on the following equation:

$$E = \frac{(P)(e_f)(1-C_c C_t)}{2,000}$$

where

E is the emission rate, tons/yr

e_f is the emission factor (uncontrolled), lb/ton

P is the production rate, tons/yr

C_c is the average operating efficiency of control equipment

C_t is the percentage of the production capacity on which control equipment has been installed.

Information required to use this equation was obtained from the literature and information survey. In cases where information was inadequate for this calculation method, emission rates were estimated from material balances, grain loadings, or some other technique. These procedures vary from case to case and are described in detail in Section 4.

Incineration (municipal, industrial and open burning) was not handled in the same manner as the other industrial sources and, in fact, was not considered an industrial source. It is, however, an important source. The total particulate emitted per year from incineration was estimated at 931,000 tons.

In developing the ranking of stationary sources represented in Table S-1, more attention was directed to calculating the emissions from the primary pieces of processing equipment such as kilns, furnaces, reactors, and dryers. In several cases, we have included emissions for "secondary sources" which include crushing, materials handling, grinding, stock piles, etc. The calculations involving these secondary sources are in general much less accurate than those involving the primary processing equipment because

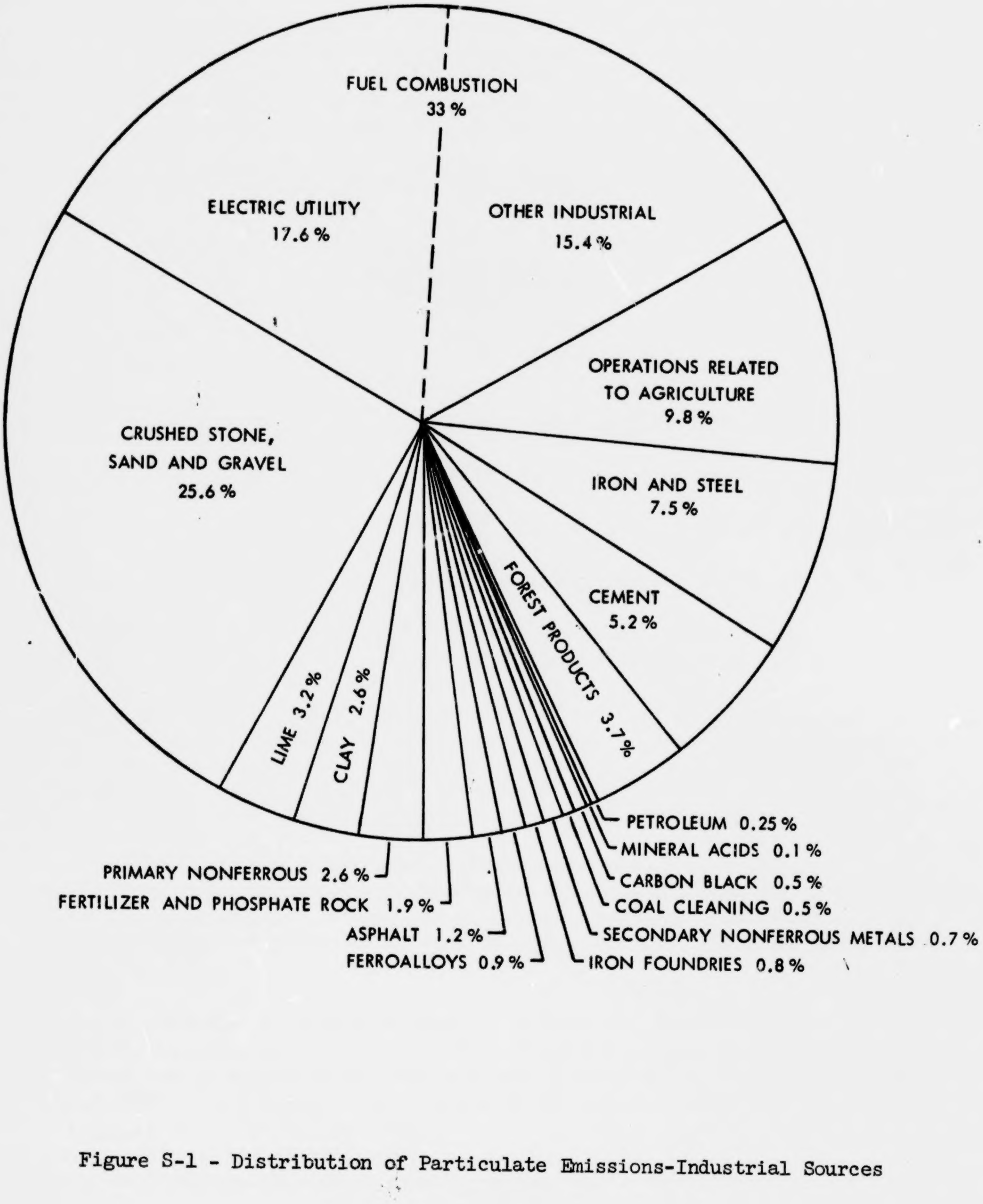

Figure S-1 - Distribution of Particulate Emissions-Industrial Sources

TABLE S-1

MAJOR INDUSTRIAL SOURCES OF PARTICULATE POLLUTION

Source	Emissions, per Table 4.1-1 Tons/Year	Emissions, Assuming That Annual Collection Efficiency is 90% of Efficiency Shown in Table 4.1-1 Tons/Year
1. Fuel Combustion	5,953,000	8,624,000
2. Crushed Stone, Sand & Gravel	4,600,000	4,714,000
3. Agricultural Operations (grain elevators, feed mills and cotton gins)	1,817,000	1,843,000
4. Iron and Steel	1,442,000	2,183,000
5. Cement	934,000	1,629,000
6. Forest Products	580,000	1,002,000
7. Lime	573,000	708,000
8. Clay	467,000	542,000
9. Primary Nonferrous (copper, aluminum, zinc and lead)	476,000	654,000
10. Fertilizer and Phosphate Rock	328,000	337,000
11. Asphalt (batch plants and roofing)	218,000	721,000
12. Ferroalloy	160,000	180,000
13. Iron Foundries	143,000	148,000
14. Secondary Nonferrous (copper, aluminum, zinc and lead)	127,000	134,000
15. Coal Cleaning	94,000	94,000
16. Carbon Black	93,000	93,000
17. Petroleum	45,000	45,000
18. Acids (sulfuric and phosphoric)	16,000	28,000
Total	18,056,000	23,679,000

data on secondary sources are meager or nonexistent. The emission quantities listed for these secondary sources are at best order of magnitude calculations, and it is possible that secondary sources may emit as much or more particulate matter than the primary sources. An example of this is the potential emission from stock piles in the crushed stone and sand and gravel industries. Results in Section 4.3.2, page 75, indicate that the potential emission from these stockpiles may be over 9 million tons per year. We have not included this number in Table S-1 because the emission figure is based on very rough estimates of stockpile losses. However, the importance of these secondary sources should not be overlooked. Secondary sources are discussed in more detail in Section 4, page 49.

The emission figures shown in the left-hand column of Table S-1 were calculated using estimated efficiencies for control equipment. Estimated efficiencies were required because most plants have not tested their equipment to determine actual operating efficiences. These estimates tend to be near the higher end of the efficiency ranges for each type of control device, and, therefore, are more representative of the optimum efficiency for these devices.

It is likely that the actual collection efficiencies would be lower than the optimum value because of equipment malfunction and operating methods. It is difficult, however, to assess what the average annual efficiency might be for a specific industry. A computation of emissions, using an annual average efficiency of 90% of the optimum efficiency listed in Table 4.1-1, page 50, was performed to provide an estimate of the probable maximum quantity of particulate emissions from the major industrial sources. The right-hand column of Table S-1 presents the results of this calculation using the annual collection efficiency results in a 32% increase in particulate emissions.

Other Ranking Methods

Objectionability

As indicated earlier in this summary, the deleterious effects created by particulate emissions result not only from the total amount emitted, but also from the physical and chemical properties of the particulates and the carrier gas. The ranking of air pollutants and their sources on the basis of objectionability is quite difficult for several reasons: (1) the dissimilarity of properties which are considered objectionable; (2) the highly subjective nature of much of the available data; and, (3) the unavoidable dependency of objectionability on the geographical and meteorological relationships of the sources and receptors. By definition an objectionable property of a pollutant is one which causes objections from humans because it produces an undesirable effect on some type of receptor (animal, plant, or material). An objectionable source is one which emits one or more of these objectionable pollutants in a location where they can cause one or more of these effects.

A brief outline of the objectionable properties of air pollutants and general effects on receptors is given in Table S-2.

In regard to the specific area of particulate pollutants from stationary sources, several of the above categories are of marginal pertinence. For example, malodorous effluents are highly objectionable air pollutants but they consist largely of gaseous, rather than particulate, materials, although the odoriferous compound may also interact with the solid particle (e.g., be absorbed, transported, and released), or be in solution in liquid mists. Nevertheless, in the present study some consideration was given to each category.

A comprehensive objectionability rating of particulate pollution sources should consider (a) the total tonnage emitted, (b) the size distribution and the chemical composition of the particles, (c) the composition of the carrier gas, (d) all potential receptors, and (e) sources parameters which may modify emissions. Obvious factors which influence the objectionability of a source include the manner in which the pollutant is emitted, the dispersion of the pollutant before it reaches a receptor, meteorological and geographical conditions, and the location, density, or nature of surrounding population, vegetation or structures, i.e., the receptors. In order to place the rating system on some objective basis, the quantification of several parameters is required.

One subjective method of ranking sources is based on citizen complaints. The results of such a ranking are shown in Table 6.3-1 to Table 6.3-4, pages 249 to 252. In a survey of air pollution control agencies, it was found that the primary metals industry was responsible for the greatest number of complaints. On the basis of a single operation, asphalt plants received the highest number of complaints.

Another ranking technique was based on toxicity and the average background levels of various toxic pollutants in the atmosphere. The results of this technique are shown in Tables 6.4-1 to 6.5-1, pages 254 to 259. Based on this ranking technique, the heavy metal particulates are the most serious pollutants; lead and mercury are ranked at the top. One significant point is that in one city the background level of mercury attained a value as high as 28% of the threshold limit value.

TABLE S-2

OBJECTIONABLE PROPERTIES OF AIR POLLUTANTS AND GENERAL EFFECTS ON RECEPTORS

I. Toxicological and sensory effects on humans

- (a) acute toxicity
- (b) chronic toxicity
- (c) irritation of eyes, lungs, mucus membranes, skin, etc.
- (d) odor

II. Effects on plant and animal life

- (a) toxic to agricultural crops, timber, grass
- (b) toxic to livestock and wildlife

III. Effects on materials and facilities

- (a) soiling
- (b) corrosive to metals, minerals, plastics, textiles, and paint
- (c) effects on electrical systems
- (d) miscellaneous (abrasive, forms sludges, etc.)

IV. Optical and esthetic effects

- (a) visibility reduction
- (b) visible or colored plume and colored atmosphere

V. Modification of atmospheric chemical and physical properties

Another ranking technique that was used was the effect of particulate pollutants on materials and facilities. These effects can range from the deposition of a dust covering to the complete dissolution by corrosion. This ranking technique was based on the cost of cleaning or replacing the material that was affected by the pollutant. The results of this technique are presented in Tables 6.6-1 and 6.6-2, pages 264 and 265, and indicate that paint, zinc, flat glass, and cement are the materials most affected by deterioration and soiling.

Two overall ranking techniques were then developed based on the individual rating systems just discussed. The first of these overall ranking techniques was based on the overall objectionability of the pollutant itself. In this ranking technique the concept of an air quality goal was employed. The air quality goal should not be confused with air quality standards, which are being set by various governmental bodies. Unfortunately, a complete set of standards is not yet available and we have, therefore, developed a set of eight air quality goals. These assigned goals are based upon several considerations including toxicity to man, animal, and plant life; corrosion and soiling of materials, odor, reduction of visibility, and formation of haze. The results of this ranking are presented in Table S-3.

The ranking of sources on the basis of overall objectionability is extremely difficult because of the large ranges in the factors which affect the quantity and type of particulate emitted by a given type of source, and a lack of data on the chemical composition and physical properties of the emitted pollutants. Table S-4 presents a ranking, on a relative scale, of the major particulate sources on the basis of their contribution to the overall problems of soiling, corrosion, toxicity, and odor. In making these rankings, consideration was given to the number, distribution, and proximity to the materials of the sources, the nature and tonnage of pollutants emitted by a typical source, and the total tonnage emitted throughout the country. This estimate includes the average control in use.

Difficulty of Control

To discuss particulate pollution sources in terms of difficulty of control, it was necessary to select a set of guidelines to judge the degree of difficulty. A review of the pertinent effluent characteristics and process variables indicated that the most significant factors are: (1) particle size distribution of emitted particulates; (2) grain loading; (3) carrier-gas volumetric flowrate; (4) particulate and carrier-gas handling characteristics (i.e., corrosive, sticky, etc.); (5) number of small sources (i.e., transfer points); and (6) nature of process.

A division of sources into the broad categories of metallurgical, chemical, combustion, and mechanical processes also facilitates a ranking of

TABLE S-3

RANKING OF AIR POLLUTANTS BY AIR QUALITY GOALS

Air Pollutant	Relative Ranking*	Basis of Ranking
Carcinogens	0.001	toxicity
Beryllium, Mercury	0.1	toxicity
Highly toxic metals (Cd, Cr, Pb, Se, V, etc.)	1	toxicity
Mercaptans	5	odor and toxicity
Isocyanates	5	toxicity
Asbestos, silica, silicates	5	toxicity
Very toxic metals (As, Sb, Cu, Ni, W)	5	toxicity
Fluorides, as HF	10	vegetation damage
Alkyl amines	20	odor, toxicity
Hydrogen sulfide	30	toxicity, corrosion (paint), (odor?)
Calcium oxide and other alkalis	30	toxicity
Mineral acids (HCl, HNO_3, H_2SO_4, H_3PO_4)	50	toxicity, corrosivity, soiling
Sulfates, nitrates, fluorides (as salts)	50	toxicity, vegetation damage electrical conductivity
Sulfur oxides	50	toxicity, vegetation damage
Organo sulfides and pyridines	50	odor and toxicity
Nitrogen oxides	50	toxicity, color, atm. rxns.
Chlorine	50	toxicity, corrosivity (odor?)
Soot, smoke, carbon black	50	soiling, toxicity
Less toxic metals (Fe, Mn, Mo, Ti, Zn, etc.)	50	soiling, toxicity
Fly ash (from coal combustion)	75	soiling, toxicity
Inert particulates	100	soiling, visibility
Oxidants (ozone, etc.) total	100	corrosion, toxicity
Olefins, aldehydes, phenols, aniline	100	toxicity, soiling, corrosion
Aromatics, chlorocarbons, mixed organics	200	toxicity, soiling
Ammonia	500	toxicity, atm. rxns. (odor?)
Hydrocarbons (excluding CH_4)	500	soiling, toxicity, atm. rxns.
Carbon monoxide	3,500	toxicity

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* Ranked in order of decreasing objectionability; i.e., a low number indicates a highly objectionable pollutant. Numerical values were chosen to correspond with maximum tolerable level in $\mu g/m^3$ during occasional 1-5 day pollution episodes.

TABLE S-4

RANKING OF AIR POLLUTION SOURCES ON THE BASIS OF OVERALL OBJECTIONABILITY

Sources*	Soiling	Corrosivity	Odor	Toxicity
Electric Utilities				
Coal-fired	C	C	C	C
Oil-fired	B	B	A	B
Gas-fired	A	A	-	-
Heating Plants				
Coal	C	C	C	C
Oil	C	C	A	B
Gas	A	A	-	-
Wood, etc.	C	B	A	C
Incinerators				
Industrial	C	B	A	B
Commercial	C	B	A	B
Municipal	C	B	A	B
Residential & Apartment	C	B	A	B
Mining and Quarrying				
Iron	C	B	-	A
Copper	C	A	-	A
Lead	C	A	-	B
Zinc	C	A	-	A
Aluminum	C	A	-	A
Nonmetals	C	A	A	A
Ferrous Metals				
Taconite handling	C	C	-	A
Steel furnaces	C	C	A	C
Foundries	C	C	A	C
Finished products	B	A	-	A
Nonferrous Metals				
Aluminum	C	C	A	C
Copper	C	B	C	B
Lead	C	B	C	C
Zinc and brass	C	B	C	B
Minor Metals and Metalloids (Production and Use)				
Arsenic	A	A	-	B
Beryllium	A	A	-	B
Cadmium	A	A	-	C
Cobalt	A	A	-	A
Chromium	A	A	-	C
Phosphorus	A	A	-	A
Manganese	A	A	-	B
Mercury	A	A	-	C
Molybdenum	A	A	-	B
Tin	A	A	-	A
Titanium	A	A	-	A
Vanadium	A	A	-	C
Food Products				
Meat processing	B	A	C	B
Grain and grain products	C	-	C	C
Food Products (Concluded)				
Sugar, candy, and confections	A	-	A	-
Coffee	B	-	B	B
Fats and oils	B	A	A	A
Textile Products				
Mills	B	B	A	B
Forest Products				
Wood	C	A	A	-
Pulp and paper	C	B	C	B
Chemicals				
Ammonia	A	B	A	A
Chlor-alkali	A	B	A	B
Mineral acids	B	C	B	C
Pigments	C	B	A	A
Coal tar products	B	B	B	C
Carbon black	C	A	-	A
Soap and detergent	-	B	B	A
Plastics and resins	C	C	B	C
Synthetic fibers	C	C	B	C
Synthetic rubber	C	B	B	B
Agricultural chemicals	C	B	C	C
Fertilizers	C	C	B	C
Paints and varnish, etc.	C	C	C	C
Polishes	A	A	A	A
Toilet and sanitation goods	A	A	A	A
Inks	B	A	A	A
Glue and gelatin	B	A	A	A
Explosives	A	A	A	A
Petroleum Refining and Related Industries	C	C	C	C
Rubber Goods	C	A	A	A
Leather Products	A	A	A	A
Glass Products	C	B	A	C
Stone and Clay Products				
Asbestos products	C	A	-	C
Abrasives	A	A	A	A
Brick and tile	C	A	-	A
Ceramics	B	A	A	B
Perlite, rock wool	B	A	A	B
Gypsum products	C	B	A	B
Crushed stone	C	A	-	A
Cement Production	C	B	A	B
Lime Production	C	B	A	B
Asphalt				
Batching	C	A	B	C
Roofing	C	A	C	B

* Ranking System
C = Serious and/or frequent problem
B = Significant local problem
A = Occasional problem
Dash (-) indicates little or no problem

Ranked on the basis of existing conditions in the United States of population distribution, controls used, etc.

difficult sources. The metallurgical, chemical, and combustion processes are inherently more difficult to control than are mechanical processes. Metallurgical processes include some of the most difficult sources to control because metallurgical effluent streams are characterized by fine metallic fumes (less than 1 μ) and high volumetric flow rates. In many cases, the particulates are corrosive, sticky, and have high angles of repose. In addition, the carrier gases are at high temperatures and may be corrosive.

Particulates emitted from mechanical processes are generally not inherently difficult to control, but the number of sources may present a problem. Conveyor transfer points, loading and unloading operations, and stockpiles may be quite troublesome. The ranking of sources by difficulty of control is presented in Section 7.

Unit Operations

Particulate emission sources can also be ranked by unit operation. A ranking on this basis delineates similarities and differences between emissions from a specific unit operation in different industries. The ranking could be developed in terms of tonnage of emitted particulate or appropriate effluent characteristics. Data on emission and production figures were found to be incomplete for many unit operations in specific industries, and a meaningful ranking on the basis of tonnage emitted could not be developed. As a consequence, a ranking or classification using effluent characteristics was developed. The unit operations considered are: (1) kilns; (2) dryers; (3) sinter machines; (4) roasters; (5) furnaces; (6) crushing, grinding, and milling; and (7) miscellaneous chemical processes. Table 7.2-1, page 283, presents the listing of particulate sources by unit operation.

Effluents

The intelligent selection or design of dust collection equipment must be based on particle and carrier gas characteristics. To facilitate a more comprehensive definition of the particulate air pollution problem, and to provide background data for control equipment design, information on effluent properties was collected and analyzed. Effluent property data for the major industrial particulate sources are presented in Volume III.

Particle and carrier-gas properties that are important for control device selection or design include: (1) particle size distribution and shape; (2) particle density; (3) electrical resistivity; (4) volumetric flowrate; (5) gas temperature; and (6) humidity.

Analyses of experimental methods for determining effluent properties, such as particle size and particle electrical resistivity, indicate that current techniques do not always accurately reflect "in-situ" conditions. No universal method or apparatus for particle size determination is possible, even in principle. For gas-cleaning applications, sedimentation and elutriation methods have very definite advantages because they give results in terms of settling velocity of Stokes' diameter. But these methods usually necessitate redispersion of collected particulate samples, which may be difficult, and any agglomerates present in the original aerosol cannot be reproduced in the particle size equipment. Another problem connected with sizing of industrial aerosols is the difficulty of procuring representative samples from the field because of the very large gas flows and variable conditions that characterize most industrial gas-cleaning situations.

There are a number of factors and combinations of factors which influence the apparent resistivity of particulates. Among those particle characteristics which may be important are particle size distribution, particle shape, particle temperature, surface energy characteristics, packing configuration, and chemical composition. Carrier-gas characteristics include chemical composition and temperature.

Evidence that these properties are important in the apparent resistivity of collected dust layers comes from numerous laboratory and field observations. On the basis of these observations, it is suggested that there are two distinct modes of electrical conduction in the collected layer: volume conduction and surface conduction. For any particular set of operating conditions, one or the other conduction mode may predominate.

Because of these conduction modes and their dependence on operating conditions, particle resistivities measured directly in plant flues are preferable to those measured in the laboratory. When "in-situ" measurements are compared to laboratory measurements, it is often found that the "in-situ" resistivity is 2 to 3 orders of magnitude lower. This discrepancy is most severe in the case of fly ash. Laboratory measurements of particle resistivity for fly ash are of limited value and the only meaningful measurements are those made "in situ." For other particulate materials, the discrepancy is not as serious. Essentially all electrical resistivity data currently available in the literature have been determined under laboratory conditions.

A more detailed discussion of effluent characteristics is presented in Chapter 4 of Volume III.

Controls

There is a wide array of equipment available for the control of particulate emissions. The major categories of gas cleaning devices are: (1) settling chambers; (2) cyclones; (3) wet scrubbers; (4) electrostatic precipitators; (5) fabric filters; (6) mist eliminators; and (7) afterburners. The selection of gas cleaning equipment is far from an exact science and is based on particle and carrier gas characteristics, and process, operating, construction, and economic factors. The efficiency of these devices is usually deferred on a mass emission basis. In many cases, efficiencies based on particle size or number average collected would be preferable. Current data are too limited to be of value at present in establishing efficiency based on these factors. These alternate efficiencies will become more important in the near future as stricter pollution codes are adopted.

Settling chambers are usually installed as precleaners to remove large and agglomerated particles, which can clog small-diameter cyclones and other equipment. Areas of application include natural draft exhaust from kilns and furnaces, cotton gins, and alfalfa feed mills. Cyclones are frequently used in both primary and secondary gas cleaning operations. They are used in feed and grain mills, cotton gins, fertilizer plants, petroleum refineries, hot mix asphalt plants, metallurgical operations, and chemicals, plastics, and metals manufacture.

Wet collectors and mist eliminators are used in pulp mills, fertilizer plants, lime plants, acid plants, hot mix asphalt plants, metallurgical operations, and chemicals, plastics, and metals manufacture. The high-voltage electrostatic precipitator is used at more large installations than any other type of high-efficiency collector. For many operations, such as coal-fired electric utility boilers, the high-voltage electrostatic precipitator is the only proven high-efficiency control device available. High-voltage single-stage precipitators have been used successfully to collect both solid and liquid particulate matter from smelters, steel furnaces, petroleum refineries, cement kilns, acid plants, and many other operations. Afterburners use a furnace for the combustion of gaseous and particulate matter. Afterburners are usually used to dispose of fumes, vapors, and odors when relatively small volumes of gases and low concentrations of particulate matter are involved.

As discussed in preceding paragraphs, the quantity of particulate emitted from industrial sources was, in most cases, calculated on the basis of an emission factor which relates the production rate to the quantity of particulate produced by the process. The quantity thereby obtained is that which would be emitted if no pollution control equipment were used. To determine the quantity of particulate emitted to the atmosphere, it is necessary to know the percent of production capacity that has controls (application of control), and the average efficiency of the control equipment weighted on the basis of the associated production capacity (efficiency of control). The product of the application and efficiency of control is the net control, which can be used along with the production rate and emission factor to calculate the quantity of particulate emitted to the atmosphere.

Net control data for each important source were found to be, in most cases, unobtainable from the open literature. There is some information as to the number of plants that have control equipment but no information as to the production capacity of these plants or to the plants that do not have control equipment. Industry surveys, conducted by telephone, were used to secure information on net control. The response from the cement industry exemplifies the type of information obtained by an industry survey. The person contacted in each cement plant surveyed was an individual knowledgeable about the air pollution control status in that company or plant. This person was asked about the following: (1) plant production capacity; (2) type of process; (3) number of kilns and associated capacity; (4) types of control equipment on kilns; (5) efficiency of the control equipment (design, actual, or estimated); and (6) other dust sources and type of control equipment used on these sources.

A total of 20 different persons were contacted and provided data on 47 plants representing 30% of the U. S. production capacity. Based on the results of this survey, 94.5% of the production capacity has control equipment with a weighted average efficiency of 93.6%. This yields a net control of 88.5%.

The data obtained were investigated using statistical analysis. It was concluded that the net control of 88.5% could vary ±6% at a 95% confidence limit. It was also concluded that there was no correlation between plant production capacity and net control, nor was there any correlation between production capacity by company and net control in that company.

A detailed discussion of the determination of net control for other industries is given in Section 5.

Projections of Particulate Emissions

The principal objective of this phase of the study was to predict the quantity of particulate pollutants emitted from stationary sources up to the year 2000. In making these forecasts the following factors were taken into account:

a. Changes in production capacity.

b. Improvements in control devices.

c. Action to enforce installation of control equipment.

To make these projections, it was necessary to obtain data or make assumptions regarding production trends, efficiency of currently installed control equipment, improvements in control devices, and net control in future years.

Production

Historical production data were collected on each major particulate pollutant source for the 1947-1968 period. Additionally, published forecasts were obtained from the literature covering the 1968 through 1980 period for many of these sources. In making projections, the median published forecasts were used in some cases; in all cases, they were at least employed as check points.

Historical data were projected to the year 2000 by 10-year intervals, using a variety of computerized forecasting procedures. Time series projections were made, using both linear and exponential forms, while other projections were based on correlation analyses between annual production volumes and the Index of Industrial Production and the Gross National Product.

Altogether, forecasts were made of all significant particulate pollutant sources on ten different bases. The median values and ranges resulting from these different forecasting techniques were carefully examined and evaluated. If there was no particular reason to disbelieve the results of the computer forecasts, a median value was chosen.

In other cases, still different forecasting methods were employed. Paint, asphalt, mineral products, lumber and cement, for example, were tied to forecasts of new construction activity, while fertilizer and grain production were keyed to per capita consumption trends. Coal combustion by electric utilities was based on a declining percentage of total energy production, brought about by a combination of improved generating efficiency and by greater eventual use of alternative energy sources.

Improvements in Control Devices

Improvements in control devices were accounted for through the development of a technological forecasting curve. Details of the development of this curve are given in Section 8.

Currently Installed Equipment

Data on equipment sales by industry for the year 1967 were used to estimate the efficiency of equipment presently being installed in each industry. The data based on sales were modified for those industries in which the sales of different types of control equipment do not accurately reflect actual practice. An example of this is petroleum production in which the cyclones on catalytic crackers are installed in series.

The technological growth curve and the estimates on efficiency of currently installed equipment are input data for the various projection methods.

Projection Methods

Five methods were selected to project the particulate emission burden to the year 2000:

a. Method 1 reflects no increase in control over 1969 - 1970 levels.

b. Method 2 reflects activity to establish controls on all sources.

c. Method 3 reflects activity to establish controls on all sources and also improvements in control devices.

d. Method 4 reflects activity to establish controls on all sources, improvements in control devices, and economic factors associated with installing control equipment on old plants.

e. Method 5 reflects activity to establish controls on all sources, improvements in control devices, economic factors associated with installing control equipment on old plants, and increasingly stringent emission standards.

Complete details of the projection methods are given in Section 8.

Results

Figure S-2 presents a summation of the projection of particulate emissions for all the major industrial sources. This figure shows that if there is no improvement in net control the emissions will increase from the present level of 18.0×10^6 tons/yr up to 52.6×10^6 tons/yr by the year 2000. This figure also illustrates the effect of four control strategies

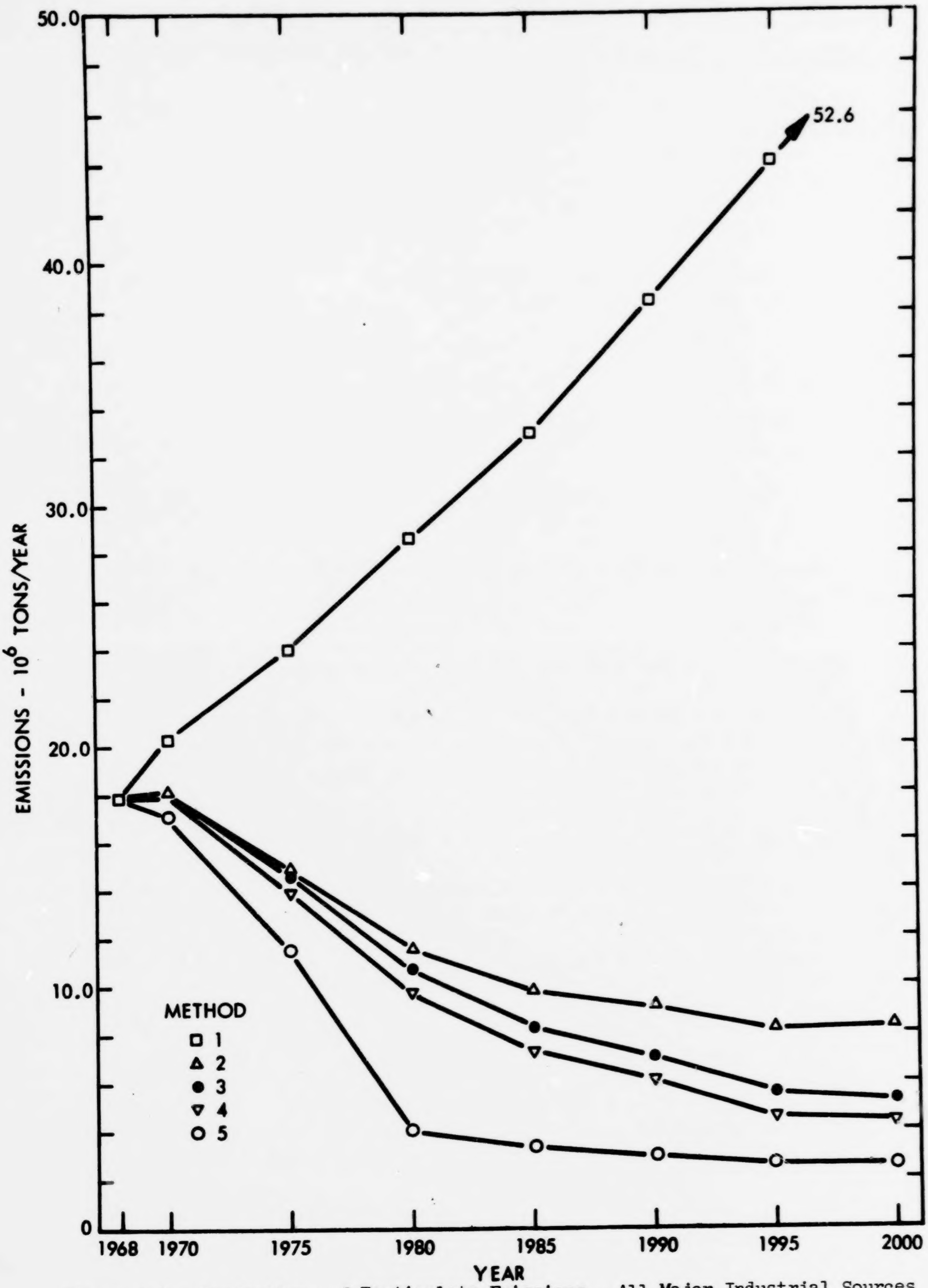

Figure S-2 - Projections of Particulate Emissions - All Major Industrial Sources that would reduce emissions to between 2.7 and 8.4 x 10^6 tons/yr in the year 2000. Results of the projection of particulate emissions from individual industrial sources are presented in Figures 8.5-2 to 8.5-27, pages 300 to 325.

The major implication of the projection of particulate emission is that emissions can be reduced by installation of control equipment on uncontrolled sources and, to a lesser extent, by shifts to more efficient types of collection equipment. Other conclusions are:

a. Emissions will rise at an alarming rate if additional and higher efficiency control equipment is not installed (Method 1).

b. The most effective method of decreasing emissions is by increasing the application of control to 100%. Accomplishing 100% application of control by 1980 (Method 5) greatly reduces emissions, especially for those industries such as electric utilities and cement in which retirement of uncontrolled plants would take a greater number of years.

c. Increasing the application of control to 100% has a pronounced effect on industries in which present application of control is low, such as crushed stone. However, this low application of control exemplifies the control difficulties involved for these industries due to the numerous and varied sources of their emissions.

d. Emissions from many industrial sources tend toward an asymptotic value after 100% application of control is achieved. Thereafter, up to the year 2000, the installation of increasingly efficient equipment tends to stabilize the quantities emitted by offsetting increased production. After the year 2000, when advances in technology have increased efficiency to 99+% emissions from most industries will follow production changes and may begin to rise accordingly.

e. Hot mix asphalt plants and coal cleaning will be serious future problems because unlike most other sources the emissions begin to rise after about 1985 even with the most severe control measures.

f. The emissions from coal-fired industrial boilers, with no change in net control (Method 1), level off after 1980 as a result of decreased use of coal in industrial boilers. This fact is corroborated by phone conversations with many industrial boiler operators who stated that they have already converted to oil or gas, or intend to do so in the next 2 or 3 years.

g. The projected emissions from primary aluminum manufacture do not decrease as significantly as in other industries under the four control methods. This situation is a result of increasing production and process characteristics that limit the suitability of efficient control devices. Further research is needed to investigate effective means of controlling this source.

h. Potential future problem sources because of magnitude of controlled emissions are:

Sources	Emissions, Year 2000
Electric Utilities	0.7 to 3.5 x 10^6 tons/yr
Crushed Stone	0.4 to 1.0 x 10^6 tons/yr
Industrial Power	0.3 to 1.0 x 10^6 tons/yr
Cement	0.2 to 0.4 x 10^6 tons/yr
Iron and Steel	0.2 to 0.4 x 10^6 tons/yr
Agriculture	0.1 to 0.3 x 10^6 tons/yr
Lime	0.1 to 0.3 x 10^6 tons/yr
Woodpulp	0.1 to 0.3 x 10^6 tons/yr
Asphalt	0.1 to 0.2 x 10^6 tons/yr
Coal Cleaning	0.1 x 10^6 tons/yr

Research and Development Plans

The objective of this phase of the project was to formulate a 5-year research and development program which would fill in gaps in knowledge about: (1) particulate sources; (2) effluent stream properties which affect control; (3) control technology; and (4) other aspects of the effects of particulate pollution and its control. These R&D 5-year programs are based on two assumed levels of support: Plan A $5 million and Plan B $1 million. The development of the R&D plans involved the identification during the program of significant knowledge gaps, the evaluation of needs for new information, considerations of the probability and degrees of success which might be attained, and estimates of the time and cost involved for each proposed research area task.

A comprehensive R&D program will require more than $5 million designated as the maximum expenditure. The more urgent problems can, however, receive a significant degree of attention within this monetary constraint.

Several significant sources were noted for which information was limited or incomplete. Largest of these in terms of tonnage of particulates emitted, and in fact, one of the largest of all sources is the crushed stone industry. The second most significant source for which more data was needed centers around agricultural products and in particular on grain elevators, flour and feed mills, cereal manufacture and associated transfer, transportation or handling facilities. The clay and ceramics industry is a third source group which is in much need of study in terms of both total emissions and constituents such as fluorides.

Knowledge gaps also exist in many aspects of the collection and measurement of particulates. These include the development and standardization of sampling and monitoring techniques and the instrumentation of these operations; the determination of the chemical composition of the collected dust from various sources and evaluation of its economic value; the more complete determination of compositions of emitted particulates; and the development of emission standards based on chemical composition as well as on a weight basis.

Areas of control technology for which further information is needed include specific operations, such as conveying and handling of materials, and a number of difficult to control, fugitive or small industry sources. The area of materials handling operations is a very significant source on an overall basis as mentioned earlier in the summary. Potential contributions of secondary sources to the particulate pollutant burden may exceed the amount generated by the primary process operations. Since there is surprisingly little definitive data on these emission sources it is imperative that a systematic research study be conducted in this area.

The control of small particle emission requires much improvement, but a general study of small particle (below 5 μ) technology will be required because of the present limitations in control capabilities in this area. Particularly troublesome are sources which emit a fine particulate at low grain loading but with a high volume of high temperature carrier gas. Metallurgical processes such as zinc retorts, aluminum reduction cells, and ferroalloys are examples which present this formidable control problem. Studies are also needed in the basic physics of growth, agglomeration, and collection of small particles to increase the understanding of these processes so that new improvements or approaches can be made in control technology.

The control of combustion sources has already received an enormous amount of attention, but because these sources constitute such a major part of the particulate problem, continuing studies are needed. The control of emissions from fossil fuel combustion is the central problem and requires further study of: control techniques for electric utility and industrial boilers; new boiler design, operating methods, and combustion techniques;

additives which improve collector efficiency; the interrelation of particulate and SO_2 control; and methods of coal desulfurization.

The detrimental and economic effects of present and projected particulate pollutant levels on health, vegetation, materials, etc., will require continuing evaluation. The interrelationships of the distribution of sources and receptors, and the economic effects of relocation of industries because of pollution related reasons need to be established. The economic effects on industry of the need to purchase new control equipment to meet increasingly stringent emission standards will need evaluation, especially for small industries and difficult to control sources where the cost of control equipment may be nearly as large as the value of the plant installation.

Particulate pollution problems whose solutions will require intensive research and development are readily identifiable and an intensive R&D program will require more than $5 million stipulated as the maximum level to be considered in the development of the present 5-year plans. The major and most urgent problems identified in the preceding paragraphs can, however, each receive a significant degree of attention within this framework. For the smaller $1 million level of effort, all but the most urgent R&D programs must be eliminated and some of these would operate at reduced levels or be delayed one or more years. Several factors were considered in determining the priority of problems and their support levels; size of the particulate burden involved; the degree to which reliable data are lacking; currently existing programs designed to solve the problem; special characteristics which make the problem important (for example, small particle sizes, toxic or carcinogenic emissions, analytical difficulties, etc.); the improvement in efficiency of control which might be obtained or the probability of successfully completing an R&D program designed to solve the problem; the time and cost involved in the proposed R&D programs; and the total level of support. Overall, an attempt was made to select R&D programs designed to give results which when added to the present state of knowledge would provide the most help in reducing the national particulate problem in the shortest time.

The total R&D program was divided into three general categories:

Area 1 - Programs on particulate sources and analysis,

Area 2 - Programs related to control technology,

Area 3 - Programs on the effects of particulate pollutants and their control.

Program topics together with the allocation of funding and the time schedule are presented in Table S-5. For more details about each program listing, see Table 9-1, page 332. At the lower level of support ($1 million) only three of the eight Area 1 programs and three of the four Area 3 programs could be included. Most of the programs which were included were necessarily assigned smaller budgets and, in addition, certain tasks had to be omitted or delayed. In both program plans, the largest portion of the expenditures was allocated to Area 2 on control technology.

The proposed R&D plans can be modified to include other or recent identified tasks of high priority or exceptionally meritorious ideas received as unsolicited proposals. In its present form it will provide the framework within which answers can be developed to some of our more urgent problems concerning the identification, effects, and control of particulate emissions.

TABLE S-5

FIVE-YEAR R&D PROGRAM COSTS ON PARTICULATE POLLUTANTS

Plan A. $5 Million Level of Support

Program Designation	Task Designation	Program Year 1	2	3	4	5	Task Totals	Program Totals
Programs on Particulate Sources and Analysis								
PS-1 Crushed Stone	PS-1.1	50,000					50,000	
	PS-1.2		50,000				50,000	100,000
PS-2 Agricultural & Related Products	PS-2.1	50,000					50,000	
	PS-2.2	40,000					40,000	
	PS-2.3		40,000				40,000	
	PS-2.4			50,000			50,000	
	PS-2.5				40,000	40,000	80,000	260,000
PS-3 Clay & Ceramics	PS-3.1			40,000			40,000	
	PS-3.2				40,000		40,000	80,000
PS-4 Miscellaneous Sources	PS-4.1	50,000					50,000	
	PS-4.2		50,000				50,000	
	PS-4.3			40,000			40,000	
	PS-4.4				40,000		40,000	
	PS-4.5					40,000	40,000	220,000
PS-5 Information Center	PS-5.1	40,000					40,000	
	PS-5.2		30,000	30,000	30,000	30,000	120,000	160,000
PS-6 Sampling & Monitoring	PS-6.1	50,000					50,000	
	PS-6.2		50,000				50,000	
	PS-6.3			75,000	75,000		150,000	
	PS-6.4					75,000	75,000	325,000
PS-7 Chemical Compositions	PS-7.1	40,000	35,000				75,000	
	PS-7.2		40,000				40,000	
	PS-7.3			45,000	45,000		90,000	
	PS-7.4					40,000	40,000	245,000
PS-8 Secondary Particulates	PS-8.1	35,000					35,000	
	PS-8.2		35,000				35,000	
	PS-8.3			40,000			40,000	110,000
Research Area I Totals		355,000	330,000	320,000	270,000	225,000		$1.500,000
Programs on Control Technology								
CT-1 Industrial, Non-Combustion Sources	CT-1.1	100,000					100,000	
	CT-1.2	50,000					50,000	
	CT-1.3		100,000	75,000	75,000	75,000	325,000	
	CT-1.4		75,000	100,000	100,000	100,000	375,000	
	CT-1.5					100,000	100,000	950,000
CT-2 Small Particle Technology	CT-2.1	70,000					70,000	
	CT-2.2		50,000	75,000	50,000		175,000	
	CT-2.3		100,000	75,000	75,000	100,000	350,000	595,000
CT-3 Combustion Sources	CT-3.1	100,000	80,000				180,000	
	CT-3.2			125,000	100,000	100,000	325,000	
	CT-3.3				100,000	50,000	150,000	
	CT-3.4					75,000	75,000	
	CT-3.5	100,000					100,000	
	CT-3.6		75,000				75,000	
	CT-3.7			50,000	50,000	50,000	150,000	1,055,000
Research Area II Totals		420,000	480,000	500,000	550,000	650,000		2,600,000

TABLE S-5 (Concluded)

Plan A. $5 Million Level (Concluded)

Program Designation	Task Designation	Program Year 1	2	3	4	5	Task Totals	Program Totals
Programs on Effects								
E-1 Effects of Control Costs	E-1.1	50,000	40,000	40,000	40,000		170,000	
	E-1.2				40,000		40,000	
	E-1.3					50,000	50,000	260,000
E-2 Effects of Pollutants	E-2.1	75,000	90,000	70,000			225,000	235,000
E-3 Toxicological Effects	E-3.1	50,000	60,000				110,000	
	E-3.2			70,000	50,000		120,000	
	E-3.3					75,000	75,000	305,000
E-4 Fundamental Studies	E-4.1	50,000					50,000	
	E-4.2				50,000		50,000	100,000
Research Area III Totals		225,000	190,000	180,000	180,000	125,000		900,000
Totals, All Programs		1,000,000	1,000,000	1,000,000	1,000,000	1,000,000		5,000,000

Plan B. $1 Million Level of Support

PS-1 Crushed Stone	PS-1.1	50,000					50,000	
	PS-1.2		50,000				50,000	100,000
PS-2 Agricultural & Related Products	PS-2.1		45,000				45,000	
	PS-2.2			40,000			40,000	
	PS-2.3				35,000		35,000	
	PS-2.4					40,000	40,000	160,000
PS-3 Clay & Ceramics	PS-3.1			40,000			40,000	
	PS-3.2				40,000		40,000	80,000
Research Area I Totals		50,000	95,000	80,000	75,000	40,000		340,000
CT-1 Industrial, Non-Combustion Sources	CT-1.1	45,000					45,000	
	CT-1.2	35,000					35,000	
	CT-1.3		40,000	35,000	35,000	50,000	160,000	240,000
CT-2 Small Particle Technology	CT-2.1	35,000					35,000	
	CT-2.2		30,000				30,000	
	CT-2.3			45,000	50,000		95,000	160,000
CT-3 Combustion Sources	CT-3.1		35,000				35,000	
	CT-3.2			40,000	40,000	75,000	155,000	190,000
Research Area II Totals		115,000	105,000	120,000	125,000	125,000		590,000
E-1 Effects of Control Costs	E-1.1	35,000					35,000	
E-2 Effects of Pollutants	E-2.1					35,000	35,000	
Research Area III Totals		35,000				35,000		70,000
Totals, All Programs		200,000	200,000	200,000	200,000	200,000		1,000,000

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1. INTRODUCTION

1.1 Background

The emission of particulate pollutants to the atmosphere can create numerous problems related to health, esthetics, and/or economics. The severity of these problems is related to the total rate of emission, the physical and chemical characteristics of the emissions, and the environment surrounding the emission source. A source particulate pollutant may therefore be important because of the total amount emitted or because of the objectionable properties of the material emitted. Deleterious aspects of particulate pollution include:

Health Problems

(1) Respiratory - created by large concentrations of particles less than 1 μ.

(2) Toxic Reaction - created by toxic particles such as fluoride salts, beryllium compounds, etc.

(3) Eye or Skin Irritation - created by acid mists or small particles.

Esthetic Problems

(1) Soiling - created by large mass emission rates, tarry or sticky emissions, etc.

(2) Turbidity (lowering of visibility) - created by emission of large concentrations of small particles (i.e., less than 1 μ).

(3) Odor - created by numerous compounds emitted by various sources.

Economic Problems

(1) Material (living and nonliving) Damage - created by corrosive particles.

(2) Soiling - cleaning costs related to soiling by particulate pollutants.

(3) Secondary Economic Problems - created by neighborhood deterioration.

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To alleviate or avert these problems requires control at the source. Adequate and economic control requires a knowledge of the sources and the properties of the effluents from the sources. Some sources are extremely difficult to control because of (a) incomplete information about sources and properties or (b) unusual properties, and research and development will be required to establish successful control techniques.

Since a large number of potentially important air pollution problems require research and development, some type of priority rating must be used to determine the optimum expenditure of funds. In the study described in the following report, we have investigated particulate pollution from stationary sources to determine the magnitude of the problem so that a priority may be developed: (a) for this area of air pollution and (b) for the problems within this area.

The results of the study are presented in the following sections of this report and in a handbook which is distinct from the report. In the following sections, the report contains program objectives and organization, more details about the handbook and final report, a discussion of information acquisition and handling, and details of emission rates and properties of effluents from source industries.

The work described in this report and the handbook is a portion of the research and development program authorized by the Clean Air Act of 1967, and implemented through the Air Pollution Control Office/EPA.

1.2 Objectives

The program was initiated to overcome deficiencies in knowledge regarding the nature of important stationary particulate pollution sources, and to provide handbook data required for the design and application of particulate control devices.

1.3 Organization of the Program

The program was organized into five phases and each phase was divided into several tasks. In these tasks we have attempted to identify, characterize, and quantify the particulate air pollution control problem for stationary sources in the USA. We have also investigated the type and magnitude of specific sources, the characteristics of both the particulates and carrier gas from specific sources, and the status of current control practices.

This organization allowed assignment of the program personnel to specific jobs, and at the same time allowed each engineer to see how his part of the program was related to the whole. The phases were divided as follows to facilitate conduct of the program:

Phase I - Sources
Phase II - Effluents
Phase III - Controls
Phase IV - Future Problems
Phase V - R&D Plans

Phase I - Sources

The two major tasks in this phase were to: (1) identify all significant sources of particulate pollutants; and (2) evaluate important particulate sources. Subtasks included: searching published and unpublished literature, consulting with air pollution control agencies, representatives of particulate pollution source industries, suppliers and users of particulate control equipment, and suppliers and operators of important classes of equipment and processes that emit particulate pollution.

The survey of various sources of information was not exhaustive, but was pursued as far as necessary to ensure that a comprehensive list of particulate sources was developed.

Important particulate sources were listed in their order of importance as contributors to the overall particulate pollution problem on the following four bases:

(1) Important sources based on total tonnage of emissions.

(2) Important sources based on objectionable properties such as toxicity, corrosiveness, or unusual soiling properties.

(3) Source classification by unit operation.

(4) Source classification by difficulty of control.

Phase II - Effluents

In this phase we attempted to characterize total effluent streams from important particulate sources. Using existing data, we have characterized particulates and carrier streams from major existing particulate pollution sources. We have included in the characterization data on particle properties such as size, shape, density, solubility, corrosive properties, hygroscopicity, agglomerating tendency, "stickiness," flowability, flammability, and toxicity.

Phase III - Controls

In this phase current particulate pollution-control practices were determined. The extent to which each of the important particulate emission sources is now controlled was determined. In addition to identifying control methods, we have included information on the performance characteristics of each method and the process stream characteristics that affect performance. We have included in the identification, control methods that have failed as well as those that are being used successfully. We have attempted to determine for different particulate sources commonality that would suggest common methods of control or common problems that tend to limit control, and identified specific particulate sources that cannot be adequately controlled by application of existing control devices or methods.

Phase IV - Future Problems

In this phase future major problem sources were predicted by studying production trends among industries that produce particulate emissions; we have attempted to predict major sources of the future to the year 2000, and to the extent possible, estimated probable emissions from major sources in tons per year.

Phase V - R&D Plans

In this phase recommendations for future research and development were developed. We have developed two 5-year research and development programs, Plan A and Plan B, as a product of this study, with Plan A based on an assumed total expenditure of $5 million and Plan B on an assumed total expenditure of $1 million.

In each plan we have analyzed data on characteristics of emissions from important sources of particulates, and as a result, recommended the specific research and development needed to advance particulate control capability. Recommended projects involve more complete characterization of particulate and carrier gas properties, and are concerned with meeting control device or control process needs that are now apparent.

We have included in each recommendation for research an evaluation of priority and a detailed description of the research proposed, including the purpose, goals, proposed scope of work, recommended approach, and estimated time and cost schedules.

1.4 Organization of the Final Report

The results of our investigations are presented in two documents--this final report and a handbook. The two documents are closely related; however, the handbook is complete in itself while the final report relies more heavily on the handbook. In our presentations we have assumed that anyone who has the final report will also have the handbook, but that persons with access to the handbook will not necessarily have access to the final report.

The final report presents, roughly, the material from Phases I, IV, and V of the program as outlined in the preceding section. This material includes the results of our investigations on source emission rates, future problems, and research and development needs. We have duplicated only those items in both documents that appear essential to a coherent presentation.

In the following sections of this report, we present the program methodology, information handling, important sources (by total tonnage, citizen complaint, objectionable properties, difficulty to control, and common unit operation), future problems, research and development plans, and conclusions.

1.5 Organization of the Handbook (Volume III)

In the handbook we present the results of our investigations on Phases II and III (Effluents and Controls) of the program. It is organized around the most important sources by total tonnage. A chapter was prepared for all sources which, when added up, contribute more than 99% of the total tonnage emitted from stationary industrial sources. Each of these chapters includes a process description, effluent properties, control techniques and control costs. There are also introductory chapters describing general effluent-property measuring techniques and general control techniques. The handbook will be referred to at appropriate places in the following report.

1.6 Bibliography

Since we have collected more than 3,000 documents in conducting our investigations, we have included only the most pertinent references in our handbook and in the final report. The bulk of these references are presented in a separate document. Several methods of grouping the references have been presented and all are stored for computer retrieval by various descriptors. More detail about our storage/retrieval capability is presented later in the report. (See Appendix A.)

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2. INFORMATION ACQUISITION

Obtaining all information pertinent to the objectives of the study was the first requirement. To do this, we conducted a rapid literature survey to find information sources. This step permitted a general definition of the scope of the information acquisition process.

Following this initial activity, the detailed information acquisition was started. The most obvious place to obtain information about any scientific subject is from the published literature. In searching public literature, abstracts of various types were extremely useful, and in this particular case the Air Pollution Control Association (APCA) abstracts or equivalent were particularly relevant. Besides this abstracting service, the Chemical Abstracts and the Engineering Abstracts, along with such government abstracts as were available, were searched for information pertaining to the study. Periodicals pertaining to specific industries or areas were sources of information. Besides the general published literature, technological libraries are a good source of information and specialized air pollution libraries contained a large amount of very useful data.

Governmental agencies dealing with air pollution problems and air pollution control were useful and productive sources of information. There are a large number of such agencies at the federal and various local governmental levels. Depending on the seriousness and the history of the air pollution problems in a particular region, these agencies had more or less information and were more or less sophisticated in their approach to the problems.

The industrial organizations which are the sources of particulate pollutants also have the information needed for a study of this type. Some industries have entered into air pollution control because of the value of the product that can be returned to their processing. Other industries use pollution-control equipment and have made pollution measurements because of public or governmental pressure. Whatever the reason for their involvement, they are in a position to have more information than anyone else on the subject of particulate pollution from their particular industries.

For most large industries, some type of an industrial or trade association has been formed, and in most cases these associations are concerned about industry-wide problems. If air pollution is one of these problems, they generally have at least some information regarding emissions, particle properties, or control techniques. The manufacturers of air pollution control equipment form another group which possesses information. The control manufacturers need this information to determine the type and size of control equipment that should be installed on a particular source.

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Companies who conduct stack-sampling tests have the exact type of information needed to determine emission rates from important sources, and in many cases they also have information on the effluent properties.

One other important information source for this study has been personal contact with persons who are conducting research on air pollution or particle physics. These contacts also have often led to other information sources, and have assisted in the formulation of research and development plans.

After determining where the information was, we used several methods of collecting the information. Ideally, we would have located every possible information source starting with those listed above, and then contacted every person or organization that might have had any information. Because this was impossible, we attempted to determine the optimum methods of contact within the constraints of manpower, time and money available. This optimum procedure was a combination of personal visits, telephone contacts and written questionnaires. A mass mailing of questionnaires was found to have two principal drawbacks: (1) the information needed is so diverse as to require a very long and complicated questionnaire; and (2) since interest was not restricted to a particular industry, it would be necessary to prepare a different questionnaire for each industry.

The procedure which has worked best for us required that the first contact be made over the telephone or by letter. Subsequent contacts were either in person or by mail, depending on the amount and quality of information that could be obtained and the wishes of the person contacted. Simplified questionnaires to a very homogeneous information source were useful. Such questionnaires were used to determine if information were available and what the nature of the information was rather than to obtain the information itself.

The actual persons contacted were determined by literature references and recommendations from previous contacts or from consultants. No standard procedure was developed in making these contacts because it was found that the particular approach used in contacting any potential information source depends on the information source itself and any prior information about the source.

After our "rapid literature and information survey" had indicated that our information sources were as complete as possible, we began to contact these sources and collect information. At the same time, we prepared a letter which was sent to over 300 air pollution control agencies which requested (1) the number of stack sampling reports that were on file; (2) the availability of any information relating to sizing, identification and characteristics of particulate or gaseous streams emanating from sources in their area; (3) information on emission inventories taken; (4) names of industrial sources who might be willing to provide information for our study; and (5) a listing of the particulate sources in their particular area which created the most problems, and the type of problems created. The results from this letter were quite good, as we received almost 150 replies, or about a 50% response. The number of air-pollution agencies with actual information of use in our study was less than 50. Subsequent telephone contacts indicated that the number possessing actual data that would be available to us was less than 30. The most commonly mentioned problem industries included hot-mix asphalt batch plants, cement plants, foundries, incinerators, and power plants. The results of this survey are discussed in more detail later in the report.

When we actually visited several local control agencies, we found data in various stages of completeness. We obtained a large amount from the New Jersey Air Pollution Control Agency, most of which gave the emission rates after control equipment. In general, they had made no attempt to determine the efficiency of the collecting equipment other than to state the type of equipment and in some cases the design efficiency. In many cases no indication was given even of the type of control equipment. However, the data from New Jersey were reasonably complete compared to the data from many other control agencies. The cooperation obtained from this control agency, as well as New York and Pennsylvania, was outstanding.

Cooperation varied from one agency to another. One agency admitted that they had a great deal of information, but seemed disinclined to divulge any of it to us. They did spend time with us in discussing problems, but would not allow us to look into their files without one of their engineers helping us, and they stated that they had no engineers available for this purpose. The average amount of information obtained from any of the 30 or so agencies that had information was approximately 10 to 15 stack sampling tests per agency. In general, almost no information on effluent properties or control parameters was obtained from these sources.

Our first contact with various technological libraries was generally by letter or in person. From general libraries such as the Linda Hall Library of Science and Technology in Kansas City, or the John Crerar Library in Chicago, we attempted to find the special information sources that might be available on air pollution. The main contribution these libraries made to our study was in the area of specific references. The NAPCA libraries at Durham and Cincinnati and the APTIC Library were especially useful and of primary importance in collecting published information for our study. Unfortunately, the APTIC Library did not go back far enough to allow us to obtain some very pertinent literature. To obtain literature information prior to 1965, we purchased the Bay Area Air Pollution Library on microfilm.

In the case of both the Bay Area Library and the APTIC Library, we found that it was more useful to scan the entire library than to attempt to use the key word descriptors that were available. We did this because it became apparent that we always missed some documents no matter how carefully we chose our key words. The basis for our literature file was then made up of the APTIC Library, the San Francisco Bay Area Library and a thorough review of the Chemical Abstracts back to the year 1950. (As we mentioned earlier, we did investigate other abstracts, but not with the thoroughness that was used in the previous three literature sources.)

In attempting to obtain information from the Air Pollution Control Manufacturers, we met with a wide variety of reactions. The gamut ranged from complete cooperation to complete lack of cooperation. When there was a lack of cooperation, three principal reasons were cited: (1) the information we were seeking gave that particular control manufacturer a competitive advantage; (2) the information was scattered throughout many files and impossible to collect; (3) Research Cottrell had a subcontract from NAPCA and was being paid to gather the information that we were requesting for free. A fourth reason was cited in some cases, i.e., that the company was newly formed and had no information. On the other end of the scale one company opened their files to us and allowed us to extract a great deal of very useful particle size information. Another control manufacturer gave us emission rate data. All of these data have been analyzed and the results are presented in the handbook.

In contacting industrial companies, the pollution sources themselves, the cooperation that we obtained depended greatly on the previous contacts they had with either federal or local air pollution agencies. The classic example of this was a cement company which was extremely cooperative with us and indicated they had emission data and particle property data which they would be willing to give to us. Two weeks after our first contact, we contacted them again to arrange for a visit to collect the data, and were told that they would not part with the data unless they were under Court Order. In the intervening 2 weeks between our first and second contacts, information that they had submitted to the local air pollution control agency in an attempt to cooperate had appeared in a letter to Congress. The purpose of this letter or report was to push for stricter legislation in air pollution, and the cement company's name had been attached to the data. This same type of complaint was voiced to us in other contacts when we said we would keep any information given to us in confidence. A frequent reply was, "I have given information to people in confidence before and seen it published." At the other extreme we made contacts with some companies who were very open with us and willing to discuss any of their problems in great detail. However, in most cases we were unable to obtain any data on emission rates or particle properties even from the companies who were most cooperative. In almost every company the data we were after, if available, were scattered throughout the company in many places and many reports, and it was not possible to collect these data without a substantial effort on the part of the industry. The most valuable assistance from companies who were cooperative was in the area of commenting on the accuracy and completeness of our information about that particular industry. Recently, several companies have offered to gather their information if we would pay them.

Industrial associations were also contacted and again our request for information about particulate pollutant sources met with a variety of reactions. If the particular industry represented by the industrial association had never been disturbed about the possible air-pollution problems in their industry, the association had little information of use to us. If, on the other hand, the industry had received a great deal of bad publicity about their air-pollution problems, the association was very protective and extremely secretive. An exception to these two statements was the National Crushed Stone Association. We attended one of their national meetings and attended a committee meeting about air pollution. Very few experiments have been run to quantify the air-pollution problems in their industry, but they are aware that they do have problems and they wish to do something about them. They pointed out to us places where information could be found and helped us to obtain it.

The method which we used to contact the associations is worth commenting on because we used three different techniques. Early in the program we sent letters to many industrial associations and scientific associations which were closely related with specific industries and that we believed might have information on particulate pollutant emissions. We received a fairly good return on these letters, but almost no information or indication that information was available. Later, we contacted some of these same associations by telephone--sometimes having a person's name and sometimes with no name, and we received a much better response. We used the last technique to become acquainted with the National Crushed Stone Association. After a telephone call to their Washington Headquarters, we were invited to attend their meeting.

Numerous individuals are involved in air-pollution work, as researchers, consultants, or in Federal or local governmental operations. We contacted this group to obtain general comments, specific information if they had it, or sources of information which we had not contacted previously. Academic researchers generally had little information of use to us because their lines of research do not coincide with the directions of this program. Their research is generally directed to fundamental studies such as particle physics (which is useful to the study) but not to emission rates or control techniques. On the other hand, engineering consultants usually offer very general information, and are helpful for an over-view of specific problems.

Persons working for Federal or local governmental agencies concerned with air pollution were good sources of information. The type of information depended on their mission, but they were generally very cooperative. We were able to obtain emission-rate data, and information sources from this group.

All three of these groups of people were cooperative; however, we did not obtain large amounts of information from any of them, but did obtain pieces of data from almost all of them.

3. COMPUTERIZED BIBLIOGRAPHIC INFORMATION RETRIEVAL SYSTEM

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3. COMPUTERIZED BIBLIOGRAPHIC INFORMATION RETRIEVAL SYSTEM

The Information Retrieval System that MRI has set up uses, as a data base, the bibliographic information from over 3,000 articles and reports that have been collected and key worded in the course of this project. All the bibliographic information and key words for each document have been entered in this computerized retrieval system along with an accession number and up to two SIC* numbers. The key words used are taken from the Microthesaurus of Air Pollution Terms.**

Retrieval of information from the data base can be done in two ways. The first method is a manual search on a single author or key word. A search by author utilizes the complete listing of documents by author which includes all bibliographic information including title of the document. A manual search by key word must rely on the selected key word list shown in Table 3-1. From this selected list one can proceed to the listing of document accession numbers under each key word. For example, if it is desired to search on the key word "scrubbers," the listing of pertinent document accession numbers is shown in Table 3-2. These accession numbers can then be used as a guide to scan titles in the complete listing of bibliographic information by document accession number.

The second retrieval method is by computerized search routines. The search program has been written to enable a search to be done by author, SIC number or key word or any combination of these utilizing up to eight key words. For example, if a computerized search was to be done on the key word "scrubbers," the computer would print out the bibliographic information for each document having this key word. A portion of this printout is shown in Table 3-3. If a computer search was done on the key word "scrubbers," but was also restricted to "SIC No. 3312" (Iron and Steel), the computer would print out the bibliographic information, as shown in Table 3-4, for only those documents that have the key word "scrubbers" and an SIC No. 3312.

The computer search routines are very versatile and allow complex combinations of author, SIC numbers and multiple key words to be used in retrieving pertinent document information. The manual search capabilities by author or single selected key words are more restricted but are still a valuable tool that will, in many cases, locate the pertinent documents without requiring use of the computer.

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* SIC - Standard Industrial Classification as prepared by the U. S. Bureau of the Budget.

** Public Health Service, Air Pollution Technical Information Center.

TABLE 3-1

SELECTED KEY WORD LIST FOR INFORMATION RETRIEVAL PURPOSES

BK-55 Plant damage
BK-119 Nitrates
BK-146 Carbon dioxide
BK-147 Carbon monoxide
BK-150 Nitrogen oxides
BK-159 Sulfur oxides
BK-163 Ozone
BK-164 Phosphorus compounds
BK-165 Phosphates
BK-171 Sulfur compounds
BK-172 Sulfates
BK-198 Combustion
BL-81 Cancer
BL-161 Electrical properties
BL-193 Air pollution episodes
BL-197 Costs
GL-07 Sonic
GL-08 Solid flow properties
GL-09 Angular properties
GL-10 Efficiency
GR-02 Respiratory diseases
GR-24 Carbon black
GR-25 Ceramics
GR-30 Cements
GR-38 Corrosion
GR-45 Aluminum
GR-49 Copper
GR-51 Iron
GR-52 Steel
GR-53 Lead
GR-63 Zinc
GR-66 Asbestos
GR-70 Limestone
GR-82 Paints
GR-84 Tar
GR-101 Economic losses
GR-104 Enforcement procedures
GR-107 Governments
GR-120 Legislation
GR-148 Standards
GR-151 Emission
GR-181 Tracers
GR-184 Mercury compounds
GR-189 Abatement
GR-191 Air quality
GY-15 Stack gases
GY-25 Particulates
GY-33 Suspended particulates
GY-36 Fumes
GY-40 Smokes
GY-53 Boilers
GY-59 Fuels
GY-60 Coal
GY-61 Coke
GY-62 Fuel gases
GY-64 Fuel oils
GY-71 Furnaces
GY-72 Basic oxygen
GY-73 Bessemer converters
GY-74 Blast
GY-75 Cupolas
GY-76 Electric
GY-77 Oil burners
GY-78 Open hearth
GY-79 Industrial emission sources
GY-81 Chemical processes
GY-84 Petroleum refining
GY-85 Kraft pulping
GY-92 Food and feed operations
GY-95 Flour
GY-96 Grain elevators
GY-97 Slaughterhouses
0-05 Sedimentation
0-06 Gravity settling
0-07 Inertial separation
0-08 Sulfur oxides control
0-12 Coal preparation processes
0-26 SO_2 removal
0-51 Instrumentation
0-81 Experimental methods
0-86 Mathematical analysis
0-95 Air pollution forecasts
P-01 Dispersion
P-02 Diffusion

TABLE 3-1 (Concluded)

P-03	Diffusion models
P-05	Plume behavior
P-16	Meteorology
P-53	Acids
P-81	Ammonia
P-83	Arsenic compounds
R-06	Measurement methods
R-14	Particle counters
R-20	Orsat analysis
R-28	Particulate classification methods
R-29	Particle shape
R-30	Particle size
R-31	Sieve analysis
R-32	Sampling methods
R-35	Particulate sampling
R-36	Samplers
R-44	Sampling probes
R-45	Stack sampling
R-47	Control equipment
R-48	Afterburners
R-54	Centrifugal separators
R-55	Settling chambers
R-56	Electrostatic precipitation
R-57	Exhaust systems
R-59	Filters
R-65	Flares
R-68	Scrubbers
R-92	Incineration
S-00	Fluorides
S-14	Hydrocarbons
S-54	Polynuclear compounds
S-78	Aluminum compounds
S-82	Beryllium compounds
S-96	Lead compounds
W-99	Automotive emissions
Y-04	Kilns
Y-05	Lime
Y-08	Mineral processing
Y-09	Mining
Y-10	Paint manufacturing
Y-11	Paper manufacturing
Y-13	Petroleum production
Y-21	Primary metallurgical processes
Y-22	Printing
Y-23	Rubber manufacturing
Y-24	Soaps
Y-28	Crop spraying
Y-30	Feed lots
Y-31	Fertilizing
Y-33	Open burning
Y-39	Solid waste disposal
Y-45	Water pollution
Y-47	Oxygen lancing
Y-49	Sintering
Y-50	Stacks
Y-59	Internal combustion
Y-72	Air quality measurements
Y-81	Dust fall
Y-82	Emission inventories
Y-89	Analytical methods
Y-90	Chemical
Y-95	Chromatography

TABLE 3-2

LISTING OF DOCUMENT ACCESSION NUMBERS FOR KEY WORD "SCRUBBERS"

R 68 Scrubbers

A 4
A 7
A 14
A 23
A 24
A 35
A 47
A 57
A 63
A 103
A 132
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R 97
R 99
R 102
R 116
R 119
R 218

TABLE 3-3

SAMPLE PORTION OF COMPUTER PRINTOUT FOR KEY WORD "SCRUBBERS"

```
SEARCH REQUEST


   ACCESSION NUMBER

   SIC CODE              0      0

   AUTHOR

   SUBJECT              AND SCRUBBERS


 1 AUTHOR               BARNES,T M,  LOWNIE, JR.,H W
   AGENCY               DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
   TITLE                A COST-ANALYSIS OF AIR-POLLUTION CONTROLS IN THE INTEGRATED IRON AND STEEL INDUSTRY
   SOURCE               AGENCY REPORT
   ACCESSION NUMBER     A   4
   SIC CODE             9110        0
   DATE                  5/69


 2 AUTHOR               LEWIS,C J,  CROCKER,B B
   AGENCY               TI-2 CHEMICAL COMMITTEE
   TITLE                THE LIME INDUSTRY?S PROBLEM OF AIRBORNE DUST
   SOURCE               JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION
   ACCESSION NUMBER     A   7
   SIC CODE             3274        0
   DATE                  1/69


 3 AUTHOR               CROSS,F L,  ROSS,R W
   AGENCY
   TITLE                FIELD CONTROL OF A DOLOMITE PLANT
   SOURCE               JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION
   ACCESSION NUMBER     A  14
   SIC CODE             3274        0
   DATE                  1/68
```

2 OF 6

PB

203128

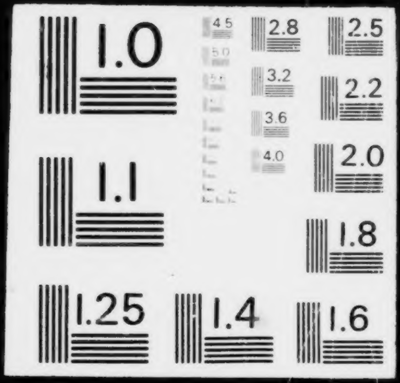

TABLE 3-3 (Continued)

```
4 AUTHOR                 SILVERMAN.L.  DAVIDSON.R A
  AGENCY
  TITLE                  ELECTRIC FURNACE FERROSILICON FUME COLLECTION
  SOURCE                 JOURNAL OF METALS
  ACCESSION NUMBER       A  23
  SIC CODE               9111      0
  DATE                    5/56


5 AUTHOR                 BRIEF.R S.  ROSE. JR..A H.  STEPHAN.D G
  AGENCY                 U. S. PUBLIC HEALTH SERVICE
  TITLE                  PROPERTIES AND CONTROL OF ELECTRIC-ARC STEEL FURNACE FUMES
  SOURCE                 JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION
  ACCESSION NUMBER       A  24
  SIC CODE               3323      0
  DATE                    2/57


6 AUTHOR                 PETROLEUM COMMITTEE TI-3
  AGENCY
  TITLE                  THE PETROLEUM REFINING INDUSTRY--AIR POLLUTION PROBLEMS AND CONTROL METHODS
  SOURCE                 JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION
  ACCESSION NUMBER       A  35
  SIC CODE               2900      0
  DATE                    1/64


7 AUTHOR                 INGELS.R M.  SHAFFER.N R.  DANIELSON.J A
  AGENCY                 LOS ANGELES COUNTY AIR POLLUTION CONTROL DISTRICT
  TITLE                  CONTROL OF ASPHALTIC CONCRETE PLANTS IN LOS ANGELES COUNTY
  SOURCE                 JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION
  ACCESSION NUMBER       A  47
  SIC CODE               2951      0
  DATE                    2/60


8 AUTHOR                 WEBER.H J
  AGENCY
  TITLE                  METHODS OF COMBATTING AIR POLLUTION IN FERROUS AND NON-FERROUS FOUNDRIES
  SOURCE                 JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION
  ACCESSION NUMBER       A  57
  SIC CODE               3300      0
  DATE                    0/ 0


9 AUTHOR                 CALVERT.S
  AGENCY                 U. S. HEALTH SERVICE
  TITLE                  BASIC STUDY OF AIR POLLUTION CONTROL WET SCRUBBERS
  SOURCE                 PENN. STATE UNIVERSITY
  ACCESSION NUMBER       A  63
  SIC CODE               9111      0
  DATE                    9/66
```

TABLE 3-3 (Concluded)

```
10 AUTHOR              POLLOCK,W A,  TOMANY,J P,  FRIELING,G
   AGENCY
   TITLE               FLUE-GAS SCRUBBER
   SOURCE              MECHANICAL ENGINFERING
   ACCESSION NUMBER    A 103
   SIC CODE            4911       0
   DATE                 8/67


11 AUTHOR              HORVATH,H,  ROSSANO,A T
   AGENCY
   TITLE               TECHNIQUE FOR MEASURING DUST COLLECTOR EFFICIENCY AS A FUNCTION OF PARTICLE SIZE
   SOURCE              1969 APCA MEETING
   ACCESSION NUMBER    A 132
   SIC CODE            9001       0
   DATE                 6/69


12 AUTHOR              KEMPNER,S K,  SEILER,E N,  BOWMAN,D H
   AGENCY              WESTERN ELECTRIC COMPANY, INDIANAPOLIS, INDIANA
   TITLE               COMPARISON OF COMMERCIALLY AVAILABLE PLATING FUME SCRUBBERS
   SOURCE              1969 APCA MEETING
   ACCESSION NUMBER    A 138
   SIC CODE               0       0
   DATE                 6/69


13 AUTHOR              SPARKS,L E,  PILAT,M J
   AGENCY              UNIVERSITY OF WASHINGTON
   TITLE               DIFFUSION FORCES AND PARTICULATE SCRUBBER EFFICIENCIES
   SOURCE              1969 APCA MEETING
   ACCESSION NUMBER    A 139
   SIC CODE            9001       0
   DATE                 6/69


14 AUTHOR              BURDOCK,J L
   AGENCY              UOP AIR CORRECTION DIVISION, DARIEN, CONNECTICUT
   TITLE               PRESENT APPLICATIONS OF MECHANICAL COLLECTORS TO BOILERS
   SOURCE              1969 APCA MEETING
   ACCESSION NUMBER    A 151
   SIC CODE            9001       0
   DATE                 6/69


15 AUTHOR              SCHINDELER,J W
   AGENCY
   TITLE               THE EFFECT OF COMMON VARIABLFS ON CYCLONE PERFORMANCE
   SOURCE              1969 APCA MEETING
   ACCESSION NUMBER    A 152
   SIC CODE            9001       0
   DATE                 6/69
```

TABLE 3-4

COMPUTER PRINTOUT FOR KEY WORD "SCRUBBERS" AND "SIC NO. 3312"

```
ACCESSION NUMBER

SIC CODE              3312      0

AUTHOR

SUBJECT               AND SCRUBBERS


1 AUTHOR              ANONYMOUS
  AGENCY
  TITLE               FABRIC FILTER INSTALLATION
  SOURCE              AIR POLLUTION MANUAL
  ACCESSION NUMBER    A 266
  SIC CODE            3312      0
  DATE                 0/ 0


2 AUTHOR              YOUNG,P A.  PEARSON,K H.  BEALE,C O
  AGENCY
  TITLE               THE GENERATION AND TREATMENT OF SINTER PLANT DUSTS
  SOURCE              AIME BLAST FURNACE, COKE OVEN AND RAW MATERIALS CONFERENCE
  ACCESSION NUMBER    A 420
  SIC CODE            3312      0
  DATE                 0/61


3 AUTHOR              BAUM,K
  AGENCY
  TITLE               NEW DEVELOPMENTS IN THE WET SCRUBBING OF EFFLUENT GASES FROM OXYGEN STEEL WORKS
  SOURCE              STAUB
  ACCESSION NUMBER    A1017
  SIC CODE            3312      0
  DATE                10/65
```

TABLE 3-4 (Concluded)

```
4 AUTHOR                ENGELS,L H
  AGENCY
  TITLE                 FEED GAS CLEANING IN COKE-OVEN LARRY CARS
  SOURCE                STAUB
  ACCESSION NUMBER      A1018
  SIC CODE              3312       0
  DATE                  11/66


5 AUTHOR                BASSE,B
  AGENCY                CHEMICAL CONSTRUCTION CORPORATION
  TITLE                 GASES CLEANED BY THE USE OF SCRUBBERS
  SOURCE                BLAST FURNACE AND STEEL PLANT
  ACCESSION NUMBER      A1130
  SIC CODE              3312       0
  DATE                  11/56


6 AUTHOR                ANONYMOUS
  AGENCY
  TITLE                 SCRUBBING SYSTEM REMOVES DUST FROM STEEL FURNACE GAS FOR POLLUTION CONTROL
  SOURCE                CHEMICAL AND ENGINEERING NEWS
  ACCESSION NUMBER      A1426
  SIC CODE              3312       0
  DATE                   8/63


7 AUTHOR                VAJDA,S
  AGENCY                JONES AND LAUGHLIN STEEL CORP., PITTSBURGH, PA.
  TITLE                 BLUE RIBBON STEEL WITH BLUE SKIES
  SOURCE                IRON AND STEEL ENGINEER
  ACCESSION NUMBER      A1469
  SIC CODE              3312       0
  DATE                   8/68


8 AUTHOR                TOUZALIN,R E
  AGENCY                ARTHUR G. MCKEE AND COMPANY, CLEVELAND
  TITLE                 SUPERIMPOSED PRECIPITATORS
  SOURCE                JOURNAL OF METALS
  ACCESSION NUMBER      A1535
  SIC CODE              3312       0
  DATE                   4/50


9 AUTHOR                DANCY,T E
  AGENCY                JONES AND LAUGHLIN STEEL CORP.
  TITLE                 CONTROL OF COKE OVEN EMISSIONS
  SOURCE                AMERICAN IRON AND STEEL INST.
  ACCESSION NUMBER      A2395
  SIC CODE              3312       0
  DATE                   5/70
```

4. IMPORTANT SOURCES BY TONNAGE

4. IMPORTANT SOURCES BY TONNAGE

4.1 Introduction

Important particulate pollutant sources based on the total tonnage emitted per year are presented in this section. To determine which sources are important, a comprehensive list of possible significant sources was prepared. This list (Appendix B) was based primarily on pollution control equipment sales. From this list of significant sources, a ranking of the most important sources was developed by calculating total emissions using emission factors and other techniques. This ranking is presented in Table 4.1-1 and includes those industries for which the estimated emissions exceed 10,000 tons per year.

The list of sources in Table 4.1-1 has been investigated in detail during this study. The results of these investigations which pertain to emissions are presented in the following subsections and in the Handbook (Volume III). The subsections are arranged in the order of ranking in Table 4.1-1, and each subsection presents the information about one source industry. Specifically, these subsections contain the details of the calculations that led to the ranking in Table 4.1-1 and pertinent data and information sources required for the calculations.

The format for each subsection of Section 4 is as follows: a short introduction, emission points, production rate, emission factors and analysis, calculation of emission rate, and important references.

The primary method of calculating emission rates was from emission factors, using the following equation:

$$E = \frac{(P)(e_f)(1 - C_c C_t)}{2{,}000\ \text{lb/ton}}$$

where E is the emission rate, tons/year
e_f is the emission factor (uncontrolled), lb/ton
P is the production rate, tons/year
C_c is the average operating efficiency of control equipment
C_t is the percentage of the production capacity on which control equipment has been installed.

Information required to use this equation was obtained from the literature and information survey. In cases where information was inadequate for this calculation, emission rates were estimated from material balances or grain loadings. These procedures vary from case to case and are described in detail in the appropriate subsections. No attempt has been made to describe

TABLE 4.1-1

MAJOR INDUSTRIAL SOURCES OF PARTICULATE POLLUTANTS
(Based on 1968 production data)

Source	Annual Tonnage P	Emission Factor Lb/Ton ef	Efficiency[b] of Control C_c	Application[a] of Control C_t	Net[c] Control $C_c \cdot C_t$	Emissions Tons/Yr E	Reliability Rating[f]
1. Fuel Combustion							
A. Coal							
1. Electric Utility							
a. Pulverized	258,400,000 tons of coal	16A=190[d] lb/ton of coal	0.92	0.97	0.89	2,710,000	1
b. Stoker	9,900,000 tons of coal	13A=146 lb/ton of coal	0.80	0.87	0.70	217,000	1
c. Cyclone	28,700,000 tons of coal	3A=35 lb/ton of coal	0.91	0.71	0.64	182,000	1
			Total from Electric Utility Coal			3,109,000	
2. Industrial boilers							
a. Pulverized	20,000,000 tons of coal	16A=170[e] lb/ton of coal	0.85	0.95	0.81	322,000	2
b. Stoker	70,000,000 tons of coal	13A=133 lb/ton of coal	0.85	0.62	0.52	2,234,000	2
c. Cyclone	10,000,000 tons of coal	3A=31 lb/ton of coal	0.82	0.91	0.75	39,000	2
			Total from Industrial Coal			2,595,000	
B. Fuel Oil							
1. Electric Utility	7.18×10^9 gal.	0.010 lb/gal	0	0	0	36,000	2
2. Industrial							
a. Residual	7.51×10^9 gal.	0.023 lb/gal	0	0	0	87,000	2
b. Distillate	2.36×10^9 gal.	0.015 lb/gal	0	0	0	18,000	2
			Total from Fuel Oil			141,000	
C. Natural Gas & LPG							
1. Electric Utility	3.14×10^6 mil. scf	15 lb/mil. scf	0	0	0	24,000	2
2. Industrial	9.27×10^6 mil. scf	18 lb/mil. scf	0	0	0	84,000	2
			Total from Natural Gas & LPG			108,000	
		Total from Utility and Industrial Fuel Combustion				5,953,000	
2. Crushed Stone, Sand & Gravel							
A. Crushed Stone	681,000,000	17	0.80	0.25	0.20	4,554,000	4
B. Sand & Gravel	918,000,000	0.1	--	--	0	46,000	4
			Total from Crushed Stone, Sand & Gravel			4,600,000	
3. Operations Related to Agriculture							
A. Grain Elevators	177,000,000 tons grain handled		0.70	0.40	0.28	1,700,000*	3
B. Cotton Gins	11,000,000 bales	12 lb/bale	0.80	0.40	0.32	45,000	2
C. Feed Mills							
1. Alfalfa Mills	1,600,000 tons dry meal	50 lb/ton dry meal	0.85	0.50	0.42	23,000	2
2. Mills Other Than Alfalfa	8,364,000 tons	1% of production	0.85	0.50	0.42	49,000	2
			Total from Listed Agricultural Operations			1,817,000	

TABLE 4.1-1 (Continued)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency[b] of Control C_c	Application[a] of Control C_t	Net[c] Control $C_c \cdot C_t$	Emissions Tons/Yr E	Reliability Rating[f]
4. Iron and Steel							
A. Ore Crushing	82,000,000 tons of ore	2 lb/ton of ore	0	0	0	82,000	4
B. Materials Handling	131,000,000 tons of steel	10 lb/ton of steel	0.90	0.35	0.32	446,000	4
C. Pellet Plants	50,000,000 tons of pellets	--	--	--	--	80,000*	4
D. Sinter Plants	51,000,000 tons of sinter						
1. Sintering Process		20 lb/ton of sinter	0.90	1.0	0.90	51,000	2
2. Crushing, Screening, Etc.		22 lb/ton of sinter	0.90	1.0	0.90	56,000	2
E. Coke Manufacture							
1. Beehive	1,300,000 tons of coal	200 lb/ton of coal	0	0	0	130,000	2
2. By-Product	90,000,000 tons of coal	2 lb/ton of coal	0	0	0	90,000	2
3. Pushing & Quenching	91,300,000 tons of coal	0.46 lb/ton of coal	--	--	--	21,000	3
F. Blast Furnace	88,800,000 tons of iron	130 lb/ton of iron	0.99	1.0	0.99	58,000	2
G. Steel Furnaces							
1. Open Hearth	65,800,000 tons of steel	17 lb/ton of steel	0.97	0.41	0.40	337,000	2
2. Basic Oxygen	48,000,000 tons of steel	40 lb/ton of steel	0.99	1.0	0.99	10,000	2
3. Electric Arc	16,800,000 tons of steel	10 lb/ton of steel	0.99	0.79	0.78	18,000	2
H. Scarfing	131,000,000 tons of steel	3 lb/ton of steel	0.90	0.75	0.68	63,000	3
			Total from Iron and Steel			1,442,000	
5. Cement							
A. Wet Process	43,600,000 tons of cement						
1. Kilns		167 lb/ton of cement	0.94	0.94	0.88	435,000	1
2. Grinders, Dryers, etc.		25 lb/ton of cement	0.94	0.94	0.83	65,000	3
B. Dry Process	31,000,000 tons of cement						
1. Kilns		167 lb/ton of cement	0.94	0.94	0.88	310,000	1
2. Grinders, Dryers, etc.		67 lb/ton of cement	0.94	0.94	0.88	124,000	3
			Total from Cement			934,000	
6. Forest Products							
A. Wigwam Burners	27,500,000 tons of waste	10 lb/ton of waste	0	0	0	132,000	2
B. Pulp Mills							
1. Kraft Process	24,300,000 tons of pulp						
a. Recovery Furnace		150 lb/ton of pulp	0.92	0.99	0.91	164,000	2
b. Lime Kilns		45 lb/ton of pulp	0.95	0.99	0.94	33,000	2
c. Dissolving Tanks		5 lb/ton of pulp	0.90	0.33	0.30	42,000	3
2. Sulfite Process	2,500,000 tons of pulp						
a. Recovery Furnace	833,000 tons of pulp	268 lb/ton of pulp	0.92	0.99	0.91	10,000	3
3. NSSC Process	3,500,000 tons of pulp						
a. Recovery Furnace	1,167,000 tons of pulp	24 lb/ton of pulp	0.92	0.99	0.91	1,000	3
b. Fluid-Bed Reactor	525,000 tons of pulp	533 lb/ton of pulp	0.70	1.00	0.70	42,000	3
4. Bark Boilers	--	--	--	--	--	82,000*	3
C. Particleboard, etc.	--	--	--	--	--	74,000*	4
			Total from Forest Products			580,000	
7. Lime							
A. Crushing, Screening	28,000,000 tons of rock	24 lb/ton of rock	0.80	0.25	0.20	264,000	3
B. Rotary Kilns	16,200,000 tons of lime	180 lb/ton of lime	0.93	0.87	0.81	294,000	2
C. Vertical Kilns	1,800,000 tons of lime	7 lb/ton of lime	0.97	0.40	0.39	4,000	2
D. Materials Handling	18,000,000 tons of lime	5 lb/ton of lime	0.95	0.80	0.76	11,000	3
			Total from Lime			573,000	

TABLE 4.1-1 (Continued)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency[b] of Control C_c	Application[a] of Control C_t	Net[c] Control $C_c \cdot C_t$	Emissions Tons/Yr E	Reliability Rating[f]
8. Primary Nonferrous Metals							
A. Aluminum							
1. Grinding of Bauxite	13,000,000 tons of bauxite	6 lb/ton of bauxite	--	--	0.80	8,000	3
2. Calcining of Hydroxide	5,840,000 tons of alumina	200 lb/ton of alumina	--	--	0.90	58,000	3
3. Reduction Cells							
a. H. S. Soderberg	800,000 tons of aluminum	144 lb/ton of aluminum	0.40	1.0	0.40	35,000	2
b. V. S. Soderberg	700,000 tons of aluminum	84 lb/ton of aluminum	0.64	1.0	0.64	10,000	2
c. Prebake	1,755,000 tons of aluminum	63 lb/ton of aluminum	0.64	1.0	0.64	20,000	2
4. Materials Handling	3,300,000 tons of aluminum	10 lb/ton of aluminum	0.90	0.35	0.32	11,000	4
			Total from Primary Aluminum			142,000	
B. Copper							
1. Ore Crushing	170,000,000 tons of ore	2 lb/ton of ore	0	0	0	170,000	3
2. Roasting	575,000 tons of copper	168 lb/ton of Cu	0.85	1.0	0.85	7,000	3
3. Reverb. Furnace	1,437,000 tons of copper	206 lb/ton of Cu	0.95	0.85	0.81	28,000	3
4. Converters	1,437,000 tons of copper	235 lb/ton of Cu	0.95	0.85	0.81	33,000	3
5. Materials Handling	1,437,000 tons of copper	10 lb/ton of Cu	0.90	0.35	0.32	5,000	4
			Total from Primary Copper			243,000	
C. Zinc							
1. Ore Crushing	18,000,000 tons of ore	2 lb/ton of ore	0	0	0	18,000	3
2. Roasting							
a. Fluid-bed	765,000 tons of zinc	2,000 lb/ton of Zn	0.98	1.0	0.98	15,000	3
b. Ropp, multi-hearth	153,000 tons of zinc	333 lb/ton of Zn	0.85	1.0	0.85	4,000	3
3. Sintering	612,000 tons of zinc	180 lb/ton of Zn	0.95	1.0	0.95	3,000	3
4. Distillation	612,000 tons of zinc	--	--	--	--	15,000*	4
5. Materials Handling	1,020,000 tons of zinc	7 lb/ton of Zn	0.90	0.35	0.32	2,000	4
			Total from Primary Zinc			57,000	
D. Lead							
1. Ore Crushing	4,500,000 tons of ore	2 lb/ton of ore	0	0	0	4,000	3
2. Sintering	467,000 tons of lead	520 lb/ton of lead	0.95	0.90	0.86	17,000	3
3. Blast Furnace	467,000 tons of lead	250 lb/ton of lead	0.85	0.98	0.83	10,000	3
4. Dross Reverb. Furnace	467,000 tons of lead	20 lb/ton of lead	--	--	0.50	2,000	3
5. Materials Handling	467,000 tons of lead	5 lb/ton of lead	0.90	0.35	0.32	1,000	4
			Total from Primary Lead			34,000	
			Total from Primary Nonferrous			476,000	

TABLE 4.1-1 (Continued)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency[b] of Control C_c	Application[a] of Control C_t	Net[c] Control $C_c \cdot C_t$	Emissions Tons/Yr E	Reliability Rating[f]
9. Clay							
A. Ceramic							
1. Grinding	4,722,000 tons	76 lb/ton	0.80	0.75	0.60	72,000	3
2. Drying	7,870,000 tons	70 lb/ton	0.80	0.75	0.60	110,000	3
B. Refractories							
1. Kiln-Fired							
a. Calcining	688,000 tons	200 lb/ton	0.80	0.80	0.64	25,000	3
b. Drying	1,032,000 tons	70 lb/ton	0.80	0.80	0.64	13,000	3
c. Grinding	3,440,000 tons	76 lb/ton	0.80	0.80	0.64	47,000	3
2. Castable	550,000 tons	225 lb/ton	0.90	0.85	0.77	14,000	3
3. Magnesite	120,000 tons	250 lb/ton	0.80	0.70	0.56	7,000	3
4. Mortars							
a. Grinding	120,000 tons	76 lb/ton	0.80	0.75	0.60	2,000	3
b. Drying	120,000 tons	70 lb/ton	0.80	0.75	0.60	2,000	3
5. Mixes	249,000 tons	76 lb/ton	0.80	0.75	0.60	4,000	3
C. Heavy Clay Products							
1. Grinding	4,740,000 tons	76 lb/ton	0.80	0.75	0.60	72,000	3
2. Drying	7,110,000 tons	70 lb/ton	0.80	0.75	0.60	99,000	3
			Total from Clay			467,000	
10. Fertilizer and Phosphate Rock							
A. Phosphate Rock	41,300,000 tons of rock						
1. Drying		12 lb/ton	0.94	1.0	0.94	14,000	2
2. Grinding		2 lb/ton	0.97	1.0	0.97	1,000	2
3. Materials Handling		2 lb/ton	0.90	0.25	0.22	30,000	4
4. Calcining	8,260,000 tons	40 lb/ton	0.95	1.0	0.95	8,000	3
B. Fertilizers							
1. Ammonium Nitrate	2,800,000 tons of granules	--	--	--	--	28,000*	4
2. Urea	1,000,000 tons of granules	--	--	--	--	10,000*	4
3. Phosphates							
a. Rock Pulverizing	17,000,000 tons of rock	6 lb/ton of rock	0.80	1.0	0.80	10,000	2
b. Acid-Rock Reaction	4,370,000 tons of P_2O_5	48 lb/ton of P_2O_5	0.95	0.95	0.90	9,000	2
c. Granulation and Drying, etc.	18,100,000 tons of granules	195 lb/ton	0.95	0.95	0.90	169,000	2
d. Materials Handling	--	--	--	--	--	18,000*	4
e. Bagging	9,000,000 tons of granules	--	--	--	--	4,000*	4
4. Ammonium Sulfate	2,700,000 tons of granules	--	--	--	--	27,000*	4
			Total from Fertilizers and Phosphate Rock			328,000	
11. Asphalt							
A. Paving Material	251,000,000 tons of material						
1. Dryers		32 lb/ton of material	0.97	0.99	0.96	161,000	2
2. Secondary Sources		8 lb/ton of material	0.97	0.99	0.96	40,000	2
B. Roofing Material	6,264,000 tons of asphalt						
1. Blowing		4 lb/ton of asphalt	--	--	0.50	3,000	4
2. Saturator		--	--	--	--	14,000*	4
			Total from Asphalt			218,000	

TABLE 4.1-1 (Continued)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency[b] of Control C_c	Application[a] of Control C_t	Net[c] Control $C_c \cdot C_t$	Emissions Tons/Yr E	Reliability Rating[f]
12. Ferroalloys							
A. Blast Furnace	591,000 tons of ferroalloy	410 lb/ton ferroalloy	0.99	1.00	0.99	1,000	2
B. Electric Furnace	2,119,000 tons of ferroalloy	240 lb/ton ferroalloy	0.80	0.50	0.40	150,000	2
C. Materials Handling	2,710,000 tons of ferroalloy	10 lb/ton ferroalloy	0.90	0.35	0.32	9,000	4
			Total from Ferroalloys			160,000	
13. Iron Foundries							
A. Furnaces	18,000,000 tons of hot metal	16 lb/ton of metal	0.80	0.33	0.27	105,000	2
B. Materials Handling							
1. Coke, Limestone, etc.		5 lb/ton of metal	0.80	0.25	0.20	37,000	3
2. Sand	10,500,000 tons of sand	0.3 lb/ton of sand	0	0	0	1,000	3
			Total from Iron Foundries			143,000	
14. Secondary Nonferrous Metals							
A. Copper							
1. Material Preparation							
a. Wire Burning	300,000 tons insulated wire	275 lb/ton of wire	0	0	0	41,000	3
b. Sweating Furnaces	64,000 tons scrap	15 lb/ton of scrap	0.95	0.20	0.19	--	
c. Blast Furnaces	287,000 tons scrap	50 lb/ton of scrap	0.90	0.75	0.68	2,000	3
2. Smelting & Refining	1,170,000 tons scrap	70 lb/ton of scrap	0.95	0.60	0.57	17,000	2
			Total from Secondary Copper			60,000	
B. Aluminum							
1. Sweating Furnaces	500,000 tons scrap	32 lb/ton of scrap	0.95	0.20	0.19	6,000	4
2. Refining Furnaces	1,015,000 tons scrap	4 lb/ton of scrap	0.95	0.60	0.57	1,000	3
3. Chlorine Fluxing	136,000 tons Cl used	1,000 lb/ton Cl used	--	--	0.25	51,000	4
			Total from Secondary Aluminum			58,000	
C. Lead							
1. Pot Furnaces	53,000 tons scrap	0.8 lb/ton of scrap	0.95	0.95	0.90	--	
2. Blast Furnaces	119,000 tons scrap	190 lb/ton of scrap	0.95	0.95	0.90	1,000	2
3. Reverb. Furnaces	554,000 tons scrap	100 lb/ton of scrap	0.95	0.95	0.90	3,000	2
			Total from Secondary Lead			4,000	
D. Zinc							
1. Sweating Furnaces							
a. Metallic Scrap	52,000 tons of scrap	12 lb/ton of scrap	0.95	0.20	0.19	--	
b. Residual Scrap	210,000 tons of scrap	30 lb/ton of scrap	0.95	0.20	0.19	3,000	3
2. Distillation Furnace	233,000 tons Zn recovered	45 lb/ton of zinc	0.95	0.60	0.57	2,000	3
			Total from Secondary Zinc			5,000	
			Total from Secondary Nonferrous Metals			127,000	

TABLE 4.1-1 (Concluded)

Source	Annual Tonnage P	Emission Factor Lb/Ton e_f	Efficiency[b] of Control C_c	Application[a] of Control C_t	Net[c] Control $C_c \cdot C_t$	Emissions Tons/Yr E	Reliability Rating[f]
15. Coal Cleaning							
A. Thermal Dryers	73,000,000 tons dried	--	--	1.0	--	94,000*	2
16. Carbon Black							
A. Channel Process	71,000	2,300	0	0	0	82,000	1
B. Furnace Process							
1. Gas	156,000	--	--	1.0	--	5,000*	2
2. Oil	1,180,000	--	--	1.00	--	6,000*	2
			Total from Carbon Black			93,000	
17. Petroleum							
A. FCC Units	1.19×10^9 bbl. of feed	--	--	1.0	--	45,000*	3
18. Acids							
A. Sulfuric							
1. New Acid							
a. Chamber	1,000,000 tons of 100% H_2SO_4	5 lb/ton of 100% H_2SO_4	--	0	0	2,000	1
b. Contact	27,000,000 tons of 100% H_2SO_4	2 lb/ton of 100% H_2SO_4	0.95	0.90	0.85	4,000	2
2. Spent-Acid Concentrators	11,200,000 tons of spent acid	30 lb/ton of spent acid	0.95	0.85	0.80	8,000	4
B. Phosphoric							
1. Thermal Process	1,020,000 tons of P_2O_5	134 lb/ton of P_2O_5	0.97	1.0	0.97	2,000	1
			Total from Acids			16,000	
			TOTAL FROM MAJOR INDUSTRIAL SOURCES			18,056,000	

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* See specific industry section for method of calculating quantity emitted.

a/ Application of Control is defined as that fraction of the total production which has controls.

b/ Efficiency of Control is defined as the average fractional efficiency of the control equipment, prorated on the basis of production capacity.

c/ Net Control is defined as the overall level of control, and is the product of the application of control multiplied by the efficiency of control.

d,e/ Average Ash Content of Coal Used, determined by phone survey (see Section 5):

Type Boiler	(d) Elec. Util.	(e) Industrial
Pulverized	11.9%	10.6%
Stoker	11.2%	10.2%
Cyclone	11.8%	10.3%

f/ Reliability rating is indicative of the reliability of the Emissions quantity. Ratings range from 1 to 4 with 1 being the most reliable.

the source processes in detail in the following subsections because this information is given in the corresponding chapters in the Handbook. More details are also presented in the Handbook on effluent properties and controls. The details of how the operating efficiency and the percentage of production capacity on which control equipment has been installed were determined are given in a separate section (Section 5). In each of the following subsections these quantities are given without reference to Section 5.

The stationary sources represented in Table 4.1-1 were ranked by calculating the emissions from the primary pieces of processing equipment such as kilns, furnaces, reactors, and dryers. In several cases, we have included emissions for "secondary sources" which include crushing operations, materials handling, stockpiles, etc. The calculations involving these secondary sources are in general much less accurate than those involving the primary processing equipment because data on secondary sources are meager or nonexistent. The emission quantities listed for these secondary sources are, at best, order of magnitude calculations, and it is possible that secondary sources may emit as much or more particulate matter than the primary sources. Total emissions for an industry were obtained as a sum of the emissions from primary and secondary sources. A more detailed discussion of secondary sources is given in Section 4.20, page 210.

A reliability rating has been assigned to the emission quantities in Table 4.1-1. These ratings range from 1 to 4 with 1 being the most reliable. The ratings were determined by assigning a reliability rating, ranging from 1 to 5, to each of the factors used to compute the emission quantities (i.e., annual tonnage, emission factor, efficiency of control, and application of control).

The reliability of each factor was evaluated by considering the quantity of data available, the spread of the data and the source of the data. After a rating had been assigned to each of the four factors, the average rating was computed and rounded off to the nearest whole number. This value is shown in the last column of Table 4.1-1. In those cases where the emissions were calculated by a method other than using the above factors, a reliability rating was applied to the final emission quantity. The composite ratings given in Table 4.1-1 range from 1 thru 4 although they represent an average of individual ratings that ranged from 1 thru 5. This results from the fact that the annual production tonnage was considered highly reliable in most instances.

To indicate the relative magnitude of the particulate problem from stationary sources, we have prepared Table 4.1-2, which lists nonindustrial sources of particulate pollutants with their corresponding emission estimates.

TABLE 4.1-2

MISCELLANEOUS SIGNIFICANT SOURCES OF PARTICULATE POLLUTION

Source	Emissions (tons/yr)	
A. Natural Dusts		63,000,000
B. Forest Fires[2]		
1. Wildfire	37,000,000	
2. Controlled fire		
(a) slash burning	6,000,000	
(b) accumulated litter	11,000,000	
3. Agricultural burning[3]	2,400,000	56,400,000
C. Transportation[3]		
1. Motor vehicles		
(a) gasoline	420,000	
(b) diesel	260,000	
2. Aircraft	30,000	
3. Railroads	220,000	
4. Water transport	150,000	
5. Non-highway use		
(a) agriculture	79,000	
(b) commercial	12,000	
(c) construction	3,000	
(d) other	26,000	1,200,000
D. Incineration		
1. Municipal incineration[4]	98,000	
2. On-site incineration[3]	185,000	
3. Wigwam burners (excl.[3] Forest Products disposal)	35,000	
4. Open dump[3]	613,000	931,000
E. Other Minor Sources[5]		
1. Rubber from tires	300,000	
2. Cigarette smoke	230,000	
3. Cosmic dust	24,000	
4. Aerosols from spray cans	390,000	
5. Ocean salt spray	340,000	1,284,000
TOTAL		122,815,000

The amount of natural dust listed, 63,000,000 tons, was calculated from data in an article written by personnel working in soil conservation.[1] The article describes a continuing project on dust deposition at 15 stations located from New Jersey to Texas and Montana. The stations are located in rural areas at sites "protected for at least several hundred feet by surrounding ground cover that effectively prevents surface soil from blowing." At the present time, yearly averages[6] at each of the stations (data from 13 stations) range from 19 to 280 lb. of dust deposited/acre/month. The highest record for a single month is 3,616 lb/acre at Tribune, Kansas, on the Colorado border, the center of the nation's dust bowl. If the median of the range of yearly averages is taken at 150 and multiplied by the number of acres subject to wind erosion, estimated at 70,000,000, the tons of natural dust settling out of the atmosphere each year are calculated to be 63,000,000.

$$70{,}000{,}000 \text{ acres} \times \frac{150 \text{ lb. dust}}{\text{acre-month}} \times \frac{12 \text{ months}}{\text{year}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}}$$

$$= 63{,}000{,}000 \text{ tons/yr}$$

The estimates of particulate emissions from forest fires were obtained from the Forest Service of the U.S. Department of Agriculture. These estimates were made on the basis of research data on products of combustion and statistics on acres of forests burned. Data have been obtained for the amount of gas produced (CO_2, SO, hydrocarbons) from a given amount of fuel in full-scale fires. The amounts of fuel required to produce only the measured amounts of gas were calculated. It was then assumed that if fuel left the fire in other than gaseous form, it left as a solid. If it left as a solid, it was particulate. No data have been obtained on size distribution, but, in intense fires, the "particulate" would include firebrands of "quite significant size." The estimates for controlled fire are discussed in the section of Forest Products.

Also listed as miscellaneous significant sources are transportation and incineration. Estimates of particulate emissions from these sources were obtained from the National Air Pollution Control Administration. More information on incineration is presented in a chapter of the Handbook. We have included other minor sources for completeness.

The total emissions from stationary industrial sources amount to 18,173,000 tons/yr, and the miscellaneous source total is 122,415,000 tons/yr. The grand total for particulate pollutant emissions in the continental United States is estimated at 140,588,000 tons/yr.

REFERENCES

1. Smith, R. M., and P. C. Twiss, "Extensive Gaging of Dust Deposition Rates," Transactions of the Kansas Academy of Science, 68 (2) 311-321, August 31, 1965.

2. Private communication, Mr. Charles Buck, Forest Service, U. S. Department of Agriculture, July 1970.

3. "1968 NAPCA Data File of Nationwide Emissions," unpublished report, Bureau of Criteria and Standards, Division of Air Quality and Emission Data, National Air Pollution Control Administration, Durham, North Carolina.

4. "Systems Analysis Study for Reduction of Air Pollution from Refuse Incinerators," report of the Division of Process Control Engineering, National Air Pollution Control Administration, prepared by Arthur D. Little, Inc., 1970.

5. Marchesani, V. J., T. Towers and H. C. Vohlers, "Minor Sources of Air Pollutant Emissions," Journal of Air Pollution Control Association, 20 (1) 19 (1970).

6. Private communication, Prof. N. T. Woodruff, Kansas State University, Manhattan, Kansas.

4.2 Fuel Combustion in Stationary Sources

The major source of particulate pollutants from fuel combustion is the electric-utility industry. An intensive effort has been made to control air pollution from this source. However, electric utilities burn approximately 300,000,000 tons of coal per year; and the magnitude of the quantity of material consumed makes the task of pollution control a formidable one. Combustion of fuel oil and natural gas also produces a notable amount of particulate pollution, but the amount estimated for combustion of these fuels is less than 10% of that estimated for coal.

The consumers of fuel have been classified as follows:

A. Electric Utilities
B. Industrial Users
C. Residential and Commercial Users

These three classifications are listed as subheadings under each of the three types of fuel: (1) coal; (2) fuel oil; and (3) natural gas.

Emission factors used are those in the "Compilation of Air Pollutant Emission Factors,"[1] with the exception of the factor for cyclone firing. Data from Reference 3 combined with data from Reference 2 indicate that a value of 3A may be more representative for cyclone units. The emission factors for coal combustion in Reference 1 are obtained from Reference 2, in which the data for cyclone firing yield an emission factor, carried to three significant figures, of 2.47 A. Two additional items of data in Reference 3 give emission factors for cyclone firing of 14A and 21A. The calculations for these factors are as follows.

Full-load test

$$\frac{\text{gr.}}{\text{cu. ft. wet f.g.}} = \frac{1.5\ \text{gr.}}{\text{cu. ft. dry f.g. at } 12\%\ CO_2} \times \frac{12.8\%\ CO_2}{12} \times \frac{0.937\ \text{cu. ft. dry f.g.}}{\text{cu. ft. wet f.g.}} = 1.5$$

$$\frac{1.5\ \text{gr. particulate}}{\text{cu. ft.}} \times \frac{557{,}600\ \text{cu. ft.}}{\text{min.}} \times \frac{60\ \text{min.}}{\text{hr.}} \times \frac{1\ \text{hr.}}{64.4\ \text{tons coal}} \times \frac{1\ \text{lb.}}{7{,}000\ \text{gr.}}$$

$$= \frac{111\ \text{lb. particulate}}{\text{ton coal}}$$

Ash content = 7.7%

$$\frac{111}{7.7} = 14A^*$$

Partial-load test

$$1.8 \times \frac{12}{12} \times 0.934 = \frac{1.7 \text{ gr. particulate}}{\text{cu. ft. wet flue gas}}$$

$$1.7 \times 443{,}500 \times 60 \times \frac{1}{41.3} \times \frac{1}{7{,}000} = \frac{156 \text{ lb. particulate}}{\text{ton coal}}$$

Ash content = 7.4%

$$\frac{156}{7.4} = 21A$$

Averaging these factors with the data in Reference 2 yields an average of 3A, which is used here for cyclone firing.

$$\begin{array}{rcl} 44 \times 2.47A &=& 108.5A \\ 1 \times 14\ A &=& 14\ A \\ \underline{1} \times 21\ A &=& \underline{21\ A} \\ \underline{46} \qquad\quad &=& 143.5A \\ \text{Average} && 3.12A\text{, round off to 3A} \end{array}$$

---

* A = percent ash

The values for the percentage of ash in the coal used for the various firing methods are averages derived from data obtained from a survey which MRI conducted during the project. This survey covered approximately half of the electric-utility plants; of the users of coal classified as "industrial," approximately one-third of those using pulverized-coal firing, one-tenth of stoker-fired and one-fifth of cyclone-fired were surveyed.

Data on coal use by consumer category were obtained from the 1968 Minerals Yearbook.[4/] The use of coal in stoker-fired boilers in electric-utility plants in 1968 was obtained from Reference 5. In compiling this quantity, only plants which designated their burning equipment as "S" (stoker) were tabulated. Plants which designated their burning equipment as "SP" (stoker and pulverized) were not included since plants having both facilities will use stoker firing only as necessary, e.g., during peak loads. The quantity obtained was 9,900,000 tons. This quantity was subtracted from the total amount of coal used in electric-utility plants, 297,000,000 tons; the difference, 287,100,000 tons, represents coal used in cyclone and pulverized-coal firing units. The amount of coal burned by cyclone and pulverized-coal firing was calculated from estimates of future use by type of firing made for the years 1960-2000.[6] The distribution of coal usage by various types of firing used for calculating the estimates in this report are shown in Table 4.2-1.

TABLE 4.2-1

ESTIMATED DISTRIBUTION OF COAL USE BY TYPE OF FIRING

User Category	Type of Firing	Distribution
Electric Utility	Pulverized	87%
	Stoker	3
	Cyclone	10
Industrial	Pulverized	20
	Stoker	70
	Cyclone	10

Coal consumed by industrial users is utilized for purposes such as process steam as well as for power generation. Data on the amounts of coal burned for various purposes are not readily available, and no effort is made to estimate air pollution from each use. Table 4.2-1 shows that stoker firing is the prevalent firing method in industrial boilers.

The data for coal use include anthracite as well as bituminous coal and lignite.

Estimates of the quantities of particulate emissions from combustion of coal are as follows. (See footnotes d and e, Table 4.1-1, p. 55, for percent ash.) The values for "Net Control," $C_c \times C_t$, are discussed in Chapter 5, pp. 213-218.

A. Electric Utility

1. Pulverized

$$E = \frac{(258,400,000)(16 \times 11.9)(1-0.92 \times 0.97)}{2,000} = 2,710,000 \text{ tons}$$

2. Stoker

$$E = \frac{(9,900,000)(13 \times 11.2)(1-0.80 \times 0.87)}{2,000} = 217,000 \text{ tons}$$

3. Cyclone

$$E = \frac{(28,700,000)(3 \times 11.8)(1-0.91 \times 0.71)}{2,000} = 182,000 \text{ tons}$$

B. Industrial

1. Pulverized

$$E = \frac{(20,000,000)(16 \times 10.6)(1-0.85 \times 0.95)}{2,000} = 322,000 \text{ tons}$$

2. Stoker

$$E = \frac{(70,000,000)(13 \times 10.2)(1-0.85 \times 0.62)}{2,000} = 2,234,000 \text{ tons}$$

3. Cyclone

$$E = \frac{(10,000,000)(3 \times 10.3)(1-0.82 \times 0.91)}{2,000} = 39,000 \text{ tons}$$

C. Residential and Commercial

The emission factor used for this classification is that for "All Other Stokers" in Reference 1,--5A. The ash content, 6%, was obtained from conversation with coal producers.

$$E = \frac{(20,000,000)(5 \times 6)}{2,000} = 300,000 \text{ tons}$$

The percentage application of air pollution control equipment on "residential and commercial" boilers was assumed to be zero.

Data on the use of fuel oil were obtained from References 7 and 8. Reference 8 contains data by consumer classification for fuel-oil use only through 1967; use by consumer classification for 1968 was therefore estimated by the ratio of total use of fuel oil in 1968[7/] to the total for 1967. Table 4.2-2 shows the total consumptions for the 2 years and the ratios obtained.

TABLE 4.2-2

RATIOS OF FUEL OIL CONSUMPTION
1968 to 1967

	Total Consumption - Barrels		Ratio
	1967[8/]	1968[7/]	1968:1967
Residual	640,000,000	680,000,000	1.06
Distillate	829,000,000	863,000,000	1.04

The quantity consumed in 1967 for each consumer classification was then multiplied by the appropriate ratio to obtain an estimate of the 1968 consumption. Table 4.2-3 lists the estimated quantities of fuel consumed in 1968.

Estimates of the quantities of particulate emissions from combustion of fuel oil are as follows:

A. Electric Utility (Gas and Electric Power Plants)

$$E = 7{,}180{,}000{,}000\text{ gal. fuel oil} \times \frac{10\text{ lb. particulate}}{1{,}000\text{ gal.}} \times \frac{1\text{ ton}}{2{,}000\text{ lb.}}$$

$$= 36{,}000\text{ tons}$$

B. Industrial

1. Residual

$$E = 7{,}510{,}000{,}000\text{ gal. fuel oil} \times \frac{23\text{ lb. particulate}}{1{,}000\text{ gal.}} \times \frac{1\text{ ton}}{2{,}000\text{ lb.}}$$

$$= 87{,}000\text{ tons}$$

2. Distillate

$$E = 2{,}360{,}000{,}000\text{ gal. fuel oil} \times \frac{15\text{ lb. particulate}}{1{,}000\text{ gal.}} \times \frac{1\text{ ton}}{2{,}000\text{ lb.}}$$

$$= 18{,}000\text{ tons}$$

C. Residential and Commercial

$$E = 36{,}530{,}000{,}000\text{ gal. fuel oil} \times \frac{8\text{ lb. particulate}}{1{,}000\text{ gal.}} \times \frac{1\text{ ton}}{2{,}000\text{ lb.}} = 146{,}000\text{ tons}$$

Data on use of natural gas were obtained from Reference 4. Two tables (Tables 5 and 6) were used. The consumer classifications and fuel quantities obtained from Reference 4 are tabulated here under the consumer classifications listed above.

TABLE 4.2-3

ESTIMATED CONSUMPTION OF FUEL OIL IN 1968

	1967 Quantity[8] (bbl.)	Ratio	Estimated 1968 Quantity (bbl.)	Estimated 1968 Quantity (gallons)
Gas and Electric Power Plants				
Residual	158,417,000	x 1.06	167,920,000	
Distillate	2,858,000	x 1.04	2,970,000	
			170,890,000	7,180,000,000
Industrial				
Residual				
Smelters, mines and mfrs.	130,819,000			
Oil and gas company fuel	37,880,000			
	168,699,000	x 1.06	178,820,000	7,510,000,000
Distillate				
Smelters, mines and mfrs.	44,997,000			
Oil and gas company fuel	8,997,000			
	53,994,000	x 1.04	56,150,000	2,360,000,000
Residential and Commercial				
Residual				
Space heating and cooking	175,990,000			
Miscellaneous	8,794,000			
	184,784,000	x 1.06	195,870,000	
Distillate				
Space heating and cooking	501,026,000			
Miscellaneous	147,381,000			
	648,407,000	x 1.04	674,000,000	
			869,870,000	36,530,000,000

Electric Utilities		3,143,000 cu. ft.
Industrial		
Industrial	7,130,000	
Lease and plant fuel	1,240,000	
Pipeline fuel	600,000	
Other consumers (municipalities for street lighting, institutional use, etc.)	300,000	9,270,000 cu. ft.
Residential and Commercial		
Residential	4,450,000	
Commercial	1,800,000	6,250,000 cu. ft.

Estimates of the quantities of particulate emissions from the combustion of natural gas are as follows:

A. Electric Utilities

$$E = 3{,}143{,}000 \text{ million cu. ft. gas} \times \frac{15 \text{ lb. particulate}}{\text{million cu. ft.}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}}$$

$$= 24{,}000 \text{ tons}$$

B. Industrial

$$E = 9{,}270{,}000 \text{ million cu. ft. gas} \times \frac{18 \text{ lb. particulate}}{\text{million cu. ft.}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}}$$

$$= 84{,}000 \text{ tons}$$

C. Residential and Commercial

$$E = 6{,}250{,}000 \text{ million cu. ft. gas} \times \frac{19 \text{ lb. particulate}}{\text{million cu. ft.}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}}$$

$$= 59{,}000 \text{ tons}$$

A summary of particulate emissions from fuel combustion at stationary sources is shown in Table 4.2-4.

A recent survey by the Federal Power Commission[8] contains data from which emission factors can be calculated for pulverized-coal and cyclone firing. The results of the calculations are tabulated as follows:

TABLE 4.2-4

PARTICULATE EMISSIONS
FUEL COMBUSTION IN STATIONARY SOURCES

Source	Amount of Fuel Burned	Emission Factor	Efficiency of Control (C_c)	Application of Control (C_t)	Net Control ($C_c \cdot C_t$)	Emissions (tons/yr)
I. Coal						
A. Electric Utility						
1. Pulverized	258,400,000 tons	16 A*	0.92	0.97	0.89	2,710,000
2. Stoker	9,900,000	13 A	0.80	0.87	0.70	217,000
3. Cyclone	28,700,000	3 A	0.91	0.71	0.64	182,000
				Total from electric utilities		3,109,000
B. Industrial						
1. Pulverized	20,000,000	16 A	0.85	0.95	0.81	322,000
2. Stoker	70,000,000	13 A	0.85	0.62	0.52	2,234,000
3. Cyclone	10,000,000	3 A	0.82	0.91	0.75	39,000
				Total from industrial use		2,595,000
C. Residential and Commerical	20,000,000	5 A				300,000
				Total from coal		6,004,000
II. Fuel Oil						
A. Electric Utilities	7,180,000,000 gal.	10 lb/1,000 gal.				36,000
B. Industrial						
1. Residual	7,510,000,000 gal.	23 lb/1,000 gal.	--	--	--	87,000
2. Distillate	2,360,000,000 gal.	15 lb/1,000 gal.	--	--	--	18,000
C. Residential and Commercial	36,530,000,000 gal.	8 lb/1,000 gal.				146,000
				Total from fuel oil		287,000
III. Natural Gas and LPG						
A. Electric utilities	3,143,143,000 mil. cu. ft.	15 lb/mil cu. ft.	--	--	--	24,000
B. Industrial	9,270,000 mil. cu. ft.	18 lb/mil cu. ft.	--	--	--	84,000
C. Residential and Commercial	6,250,000 mil. cu. ft.	19 lb/mil cu. ft.	--	--	--	59,000
				Total from natural gas		167,000
	Total for fuel combustion, stationary sources					6,458,000

---

* A is percent ash.

	Pulverized Coal	Cyclone
Number of boilers	80	15
Arith. mean emission factor	15A	8A
Geom. mean emission factor	13A	7A
Median	15A	6A
Range	0.3A-29A	4A-25A
Std. deviation	6.02A	5.01A
Std. error of the mean	0.67A	1.29A
Coeff. of variation	0.41	0.62

The emission factors for pulverized coal, both the geometric mean, 13A, and the arithmetic mean, 15A, are in good agreement with the factor, 16A, listed in Reference 1 for "general" pulverized-coal firing. The factors for cyclone firing, 8A and 7A, respectively, for arithmetic and geometric means, are significantly higher than the factors for cyclone firing, 2A, listed in References 1 and 3A used here to estimate the particulate emissions from boilers utilizing cyclone firing.

Two plants burning fuel oil reported data which yield emission factors significantly higher than the factor for fuel-oil combustion in power plants, 10 lb. per 1,000 gal. listed in Reference 1. The emission factors obtained were 28 and 94 lb. of particulate per 1,000 gal. of fuel oil burned. The following calculations were made:

$$e_f, \frac{\text{lb. particulate}}{\text{1,000 gal. fuel oil}} = \frac{\text{cu. ft. f.g.}}{\text{min.}} \times \frac{\text{grains}}{\text{cu. ft.}} \times \frac{\text{lb.}}{\text{gr.}} \times \frac{\text{hr.}}{\text{Btu}} \times \frac{\text{Btu}}{\text{bbl.}} \times$$

$$\frac{\text{bbl.}}{\text{1,000 gal.}} \times \frac{\text{min.}}{\text{hr.}}$$

Plant A

$$e_f = 600{,}000 \times 0.06 \times \frac{1}{7{,}000} \times \frac{1}{1{,}600 \times 10^6} \times (6 \times 10^6) \times 23.8 \times 60$$

$$= 27.6 \text{ lb/1,000 gal.}$$

Plant B

$$e_f = 254{,}000 \times 0.48 \times \frac{1}{7{,}000} \times \frac{1}{1{,}600 \times 10^6} \times (6 \times 10^6) \times 23.8 \times 60$$

$$= 93.5 \text{ lb/1,000 gal.}$$

The questionnaire sent out by the Federal Power Commission requested estimated emission rates from plants that had no stack-sampling data, and the estimated values were not denoted in the data furnished. It would be desirable to ascertain the influence of the estimated emission rates on the statistics before making adjustment of the factors in current use.

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FUEL COMBUSTION

1. Duprey, R. L., "Compilation of Air Pollutant Emission Factors," Public Health Service Publication No. 999-AP-42, 1968.

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5. Keystone Coal Industry Manual, McGraw-Hill, New York, 1969.

6. Moore, W. W., "Reduction in Ambient Air Concentration of Fly Ash--Present and Future Prospects," National Conference on Air Pollution, Washington, D. C., December 12-14, 1966, Paper No. B10.

7. 1968 Minerals Yearbook, Vol. I-II, Bureau of Mines, U. S. Department of the Interior, p. 894, Table No. 44, and p. 895, Table No. 45.

8. Statistical Abstracts 1969, Bureau of the Census, U. S. Department of Commerce, Table No. 1031.

9. Private Communication, John R. O'Connor, Division of Economic Effects Research, National Air Pollution Control Administration, Raleigh, North Carolina, September 22, 1969.

4.3 Crushed Stone and Sand and Gravel

Air pollution from the crushed stone industry and the sand and gravel industry arises from materials-handling equipment, conveyors and elevators; from the sizing operations, crushing, grinding and screening; from stockpiles from which dust is blown by the wind; and from traffic of vehicles over plant roads. The raw materials for these industries, as obtained from the ground, are usually moist and not notably dusty during initial processing. The moisture content is affected by atmospheric temperature. Materials which are moist in the winter months may be dry in the summer. Some material is dredged from underwater sources. Approximately 10% of sand and gravel is presently obtained by dredging.1/

In the crushed stone industry, rock is routinely passed through jaw crushers as the first step in size reduction. Subsequent crushing is done in cone crushers and gyratory crushers as necessary to obtain desired sizes. Milling is done for materials used in finely divided form, e.g., agricultural lime.

In the sand and gravel industry, washing is often required to obtain a product which meets users' specifications. Wetting of the material tends to prevent dust from forming. A rule of thumb for minimum wash water requirements is 1 gal/min for 1 ton of finished product per 10-hr. day.2/ This amounts to 600 gal. of water/ton of product. Material is frequently screened before crushing, and wash water is applied to the material as it passes over the screens. Washing may also occur on conveyors transporting material from digging site to the plant.

Emission factors and the emissions calculated are shown in Table 4.3-1. Emission factors were obtained for the various rock crushers and for conveying, general screening, etc., in crushed stone plants; and for emissions from sand and gravel plants as a whole. No factors were obtained for rock dryers, for quarrying operations or for in-plant vehicle traffic. Values for C_c and C_t are discussed in Chapter 5, p. 218.

4.3.1 Crushed Stone

The following emission factors are listed for several grinding operations and are based on the amount of rock passing through primary crushing at one plant.3/

TABLE 4.3-1

PARTICULATE EMISSIONS
CRUSHED STONE AND SAND AND GRAVEL

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions Tons/Year
I. Crushed Stone						
A. Primary crusher	681,000,000 tons (cement, lime & dolomite not included)	0.5 lb/ton of rock[a]				
B. Secondary crushing & screening		1.5[a]				
C. Tertiary crushing & screening		6.0[a]				
D. Fines milling		6.0[a]				
E. Re-crushing & screening		1.0[b] 15.0[a]	0.80	0.25	0.20	4,100,000
F. Conveying, general screening, etc.		1.7 lb/ton of product	0.80	0.25	0.20	454,000
G. Dryers		--	--	--	--	--
II. Sand & Gravel - crushing and screening	918,000,000 tons	0.1 lb/ton of material				46,000
III. Quarrying						
A. Drilling		--	--	--	--	--
B. Blasting		--	--	--	--	--
C. Loading - unloading		--	--	--	--	--
IV. In-Plant Vehicle Traffic		--	--	--	--	--
		Total for Crushed Stone and Sand and Gravel				4,600,000

---

[a] Pounds/ton of rock through the primary crusher.

[b] Listed emission factor is 5 lb/ton of rock re-crushed. Twenty percent of product is assumed to be re-crushed.

Primary crusher	0.5 lb. dust/ton of rock through primary crusher
Secondary crushing and screening	1.5 lb. dust/ton of rock through primary crusher
Tertiary crushing and screening	6.0 lb. dust/ton of rock through primary crusher
Fines milling	6.0 lb. dust/ton of rock through primary crusher
Total for "once-through"	14.0 lb. dust/ton of rock through primary crusher
Re-crushing and screening	5 lb. dust/ton of rock re-crushed

The proportions of rock passing through tertiary crushers and mills will vary in any one plant as well as from plant to plant. However, it is assumed that the proportions of rock passing from primary crushing to the various secondary grindings at the plant where the above emission factors were measured are typical for the total industry.

Based on conversations with industry contacts, 20% of the total rock crushed is assumed to undergo re-crushing. The emission factor for re-crushing can be calculated on the basis of rock through the primary crusher as follows:

5 x 0.20 = 1 lb. of dust from re-crushing/ton of rock through the primary crusher

The total overall emission factor for crushed stone is then 15 lb. dust/ton of rock crushed in the primary crusher. Although as much as 20% of the raw material may be waste (clay, dirt, etc.), for the purpose of calculating an estimate of particulate emissions the tons of product are assumed to equal the tons of rock crushed.

Production of crushed and broken stone amounted to 816 million tons in 1968.[4] The amount of stone used in the manufacture of cement, lime, and dead-burned dolomite was subtracted from this total because particulate emissions from crushing of this stone were accounted for in emission estimates for those industries. Dimension stone is also not included. The total amount of stone used in the estimates for the crushed stone industry was determined as follows:

Total production, crushed and broken stone		816,000,000 tons
Used in cement manufacture	104,000,000	
Used in lime manufacture	28,000,000	
Dead-burned dolomite	3,000,000	
	135,000,000	

Total for estimate of particulate pollution under the heading, "Crushed Stone" 681,000,000 tons

Information available on the installation of dust-control equipment in the crushed stone industry indicates that the net control is approximately 0.20, i.e., $C_c \times C_t = (0.80)(0.25) = 0.20$. Dust discharged to the atmosphere is thus estimated as follows.

P = 681,000,000 tons of crushed rock produced in 1968 (excludes rock used for cement, lime and dolomite)

e_f = 15 lb. dust/ton of product

C_c = 80%, average operating efficiency of dust collectors installed in rock crushing plants

C_t = 25%, percent of production capacity in the industry on which dust collectors are installed

$$\frac{(681,000,000)(15)(1-0.80 \times 0.25)}{2,000} = 4,100,000 \text{ tons of dust discharged}$$

to the atmosphere in 1968 from stone crushing

4.3.2 Sand and Gravel

No information has been found on emission factors from sand and gravel plants. State air pollution control agencies in states with the largest production report that sand and gravel plants are an infrequent source of complaint. Most sand and gravel plants operate without dust collectors; many are in rural areas. Dust-control equipment has been found desirable for some plants located in metropolitan areas, and the means of control is usually a wet technique. Fabric filters are used to a lesser extent. Information on the percent of production capacity in the sand and gravel industry that is equipped with dust collectors is not readily available. The only data obtained on emission factors is one sampling report5/ which lists a value of 0.06 lb. of dust per "ton of material through the plant." No mention was made of dust collectors. This sampling was done in a temperate climate in the month of January. This report lists the "discharge of the secondary and reducing crushers," the elevator boot on the "dry side" of the plant, and the final screening on the dry side of the plant as the sources of dust. Seventy-five percent of the dust was estimated to come from the crushers.

Based on the above information, the emission factor for sand and gravel plants was assumed to be 0.1 lb. of dust/ton of product. In estimating the amount of dust emissions, no account was made for dust collectors.

Production of sand and gravel in the United States in 1968 was 918,000,000 tons.[5] Estimate of the dust generated by the industry is as follows.

$$E = 918{,}000{,}000 \times \frac{0.1}{2{,}000} = 46{,}000$$ tons of dust discharged to the atmosphere in 1968 from processing sand

Emission factors and the emissions calculated are shown in Table 4.3-1.

Dust blown from stockpiles has been estimated at 1% of finished product for sand and at 1/2% for gravel and crushed stone.[3] Most stockpiles are merely piled on the ground; however, silos and bins are sometimes used. Because of the large tonnages of production in these two industries, the total amount of dust blown from stockpiles becomes correspondingly large. Production in the two industries is widely scattered. The 1968 Minerals Yearbook lists over 4,000 crushed stone plants and over 6,000 sand and gravel plants. The total production for the two industries (excluding cement, lime and dolomite) is approximately 1,600,000,000 tons. Table 4.3-2 shows the amount of dust that would arise from stockpiles if the total of the production of the two industries were subject to dust losses at the emission rates indicated. Factors which would reduce this estimate are: (1) the amount of product which is loaded for shipment directly from processing without being sent to stockpiles, (2) the amount of product which is stored in bins and silos, and (3) material which may contain sufficient moisture at time of discharge to stockpiles to inhibit the formation of dust.

TABLE 4.3-2

DUST POTENTIAL OF STOCKPILING IN THE CRUSHED STONE AND SAND AND GRAVEL INDUSTRIES

Material (tons/year)	Emission Rate of Product	Dust Potential from Stockpiles (tons/year)
Crushed stone; 618,000,000	1/2%	3,090,000
Gravel; 548,000,000	1/2%	2,740,000
Sand; 370,000,000	1%	3,700,000

REFERENCES

CRUSHED STONE

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3. "Air Pollutant Emission Factors," report of the Division of Air Quality and Emission Data, National Air Pollution Control Administration, April, 1970, prepared by TRW Systems Group of TRW, Inc., Contract No. CPA 22-69-119, p. 4-20.

4. 1968 Minerals Yearbook, Vol. I-II, Bureau of Mines, U. S. Department of the Interior, pp. 1040-41, Table 8.

5. Ibid., p. 980, Table 1.

6. Private communication, industrial source.

4.4 Operations Related to Agriculture

Included under this heading are five operations which are directly connected to agriculture.

1. Burning of stubble
2. Grain elevators
3. Cotton gins
4. Feed mills
5. Flour mills

Four of these are industrial sources, one for which no estimate of particulate pollution is made (flour mills). The first is a farming activity (burning of stubble). Not included are such sources as dust from tilling of the soil, blowing of soil (included under Natural Dust in Table 4.1-2, "Miscellaneous Sources"), and numerous manufacturing and food industries (cereal, starch, brewing) which use agricultural products. The industries reported on here are thought to be the most significant with regard to particulate pollution among the industries connected with agriculture. The total of smaller amounts of dust from less profuse sources may also be significant.

A summary of emission factors and estimated quantities of emissions is shown in Table 4.4-1. Emission factors were obtained for all sources listed in the table except for milled feeds other than alfalfa and disposition of waste products at flour mills. Dust from mills producing these other feeds is estimated at 1% of the product. Dust from flour mills is not estimated. Values of C_c and C_t are discussed in Chapter 5, pp. 219-220.

4.4.1 Burning Stubble

An estimate of the quantity of particulate emission from the burning of stubble was provided by the National Air Pollution Control Administration.1/ The estimated quantity was derived as the product of estimates of the tonnage of stubble per acre and the number of acres on which stubble was burned, and the emission factor for open burning, 17 lb. of particulate per ton of material burned. This quantity is estimated to be 2,400,000 tons per year.

4.4.2 Grain Elevators

The emission factors used to estimate the dust emitted from grain elevators were obtained from the most recent compilations of information on this source.2,3/ Listed below are factors from Reference 3 which are derived mainly from Reference 2.

TABLE 4.4-1

PARTICULATE EMISSIONS FROM
OPERATIONS RELATED TO AGRICULTURE

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/yr)
I. Burning of Stubble	280,000,000 tons of stubble	17 lb/ton of stubble burned	0.0	0.0	0.0	2,400,000
II. Grain Elevators	177,000,000 tons of grain					
A. Terminal Elevators						
1. Shipping or Receiving		1 lb/ton of grain handled				
2. Transferring, Conveying, etc.		2 lb/ton of grain handled				
3. Screening and Cleaning		5 lb/ton of grain handled				
4. Drying		6 lb/ton of grain handled				
B. Country Elevators						
1. Shipping or Receiving		5 lb/ton of grain handled				
2. Transferring, Conveying, etc.		3 lb/ton of grain handled				
3. Screening and Cleaning		8 lb/ton of grain handled				
4. Drying		7 lb/ton of grain handled				
	Total for Grain Elevators		0.70	0.40	0.28	1,700,000
III. Cotton Gins	11,000,000 bales					
A. Trailer Unloading		5 lb/bale				
B. Cleaners		2 lb/bale				
C. Stick and Bur Machine plus Huller Front and Mote Discharge Stand		3 lb/bale				
D. Lint Cleaner		1 lb/bale				
E. Condenser		1 lb/bale				
	Total for Cotton Gins	12	0.80	0.40	0.32	45,000
IV. Feed Mills						
A. Alfalfa Dehydrators	1,600,000 tons of dry meal					
1. Primary Cooling Cyclone		11 lb/ton of dry meal				
2. Secondary Cooling Cyclone		4 lb/ton of dry meal				
3. Air-Meal Separator						
a. Cyclone		47 lb/ton of dry meal				
b. Cyclone + Skimmer		9 lb/ton of dry meal				
4. Pellet-Meal Separator		2 lb/ton of dry meal				
5. Pellet Re-Grinder		2 lb/ton of dry meal				
	Total for Alfalfa Dehydrators	50 (as an average)	0.85	0.50	0.42	23,000
B. Wheat Mill-Feeds	4,490,000 tons	1% of end product	--	--	0.42	26,000
C. Gluten Feed and Meal	1,515,000 tons	1% of end product	--	--	0.42	9,000
D. Rice Mill-Feeds	476,000 tons	1% of end product	--	--	0.42	3,000
E. Brewers' Dried Grains	336,000 tons	1% of end product	--	--	0.42	2,000
F. Distillers' Dried Grains	447,000 tons	1% of end product	--	--	0.42	3,000
G. Dried Beet Pulp	1,100,000 tons	1% of end product	--	--	0.42	6,000
	Total for Feed Mills Other Than Alfalfa					49,000
V. Flour Mills	112 lb. per capita	--	--	--	--	--
			TOTAL FOR LISTED OPERATIONS			4,217,000

Source	Emission Factor (lb/ton)
Terminal elevators	
Shipping or Receiving	1
Transferring, Conveying, etc.	2
Screening and Cleaning	5
Drying	6
Country Elevators	
Shipping and Receiving	5
Transferring, Conveying, etc.	3
Screening and Cleaning	8
Drying	7

Some grains generate more dust than others. Oats and milo (sorghum) are notoriously dusty; wheat is a comparatively clean grain. However, no data have been found to indicate the difference in dustiness between grains; therefore, no effort was made to estimate emissions for individual grains. Also, there is lack of data on amount of dust generated in unloading different types of railroad cars. Dumping grain from a boxcar generates more dust than unloading a hopper car.

In addition to loading and unloading, grain is transferred for other purposes. Conserving storage space is a constant endeavor; grain from full, small bins is combined in large bins. A desired quality of grain is obtained by blending different grades, which are transferred from different bins to make the blend. Also, to prevent deterioration, grain is "turned" in the winter to lower the storage temperature. "Turning" is the transfer of grain from one bin to another which is empty and cold. Grain can also be cooled by running it through a dryer using cold air. When turning is done, repeated exposure to low temperatures is necessary for substantial cooling.[4/] Wheat, for example, will probably be received at temperatures above 85°F; 55°F is a desirable storage temperature. Since one turning (transferring from one bin to another) will reduce the temperature less than 10°, even in the coldest weather, and since grain in a concrete bin is affected little by atmospheric temperature, frequent turning is desirable.

Grain stored in elevators is cleaned to remove dirt, chaff, etc., and dried to prevent deterioration in storage. Cleaning and drying are the dustiest operations in grain elevators.

The amount of dust discharged to the atmosphere from grain elevators was estimated from the tonnage of principal crops which would be handled in grain elevators.[5/] These are corn, wheat, soybeans, sorghum, oats, barley, rice and rye. Not all of the grain harvested goes to market. A small amount is kept for seed (a smaller amount goes to market to be sold as seed); however, most of the grain kept on farms is used for livestock feed. Among the "feed" grains, approximately 1/2 of the corn and 2/3 of oats are kept on farms. Table 4.4-2 lists quantities of grain harvested "for use as grain" and the amount "sold from farms" in 1968.[6]

TABLE 4.4-2

DISPOSITION OF GRAINS[a] HARVESTED AS GRAINS IN 1968

Grain	Total Production[b] for Grain (10^3 bushels)	Sold from Farms (10^3 bushels)	Pounds per Bushel	Sold from Farms (tons)
Corn	4,375,000	2,319,000	56	65,000,000
Wheat	1,570,000	1,471,000	60	44,000,000
Soybeans	1,080,000	1,056,000	60	32,000,000
Sorghum	738,000	596,000	56	17,000,000
Oats	930,000	348,000	32	6,000,000
Barley	418,000	310,000	48	7,000,000
Rice	105,000,000 cwt.	104,000,000 cwt.	-	5,000,000
Rye	23,000	19,000	56	500,000
Total handled in grain elevators				177,000,000

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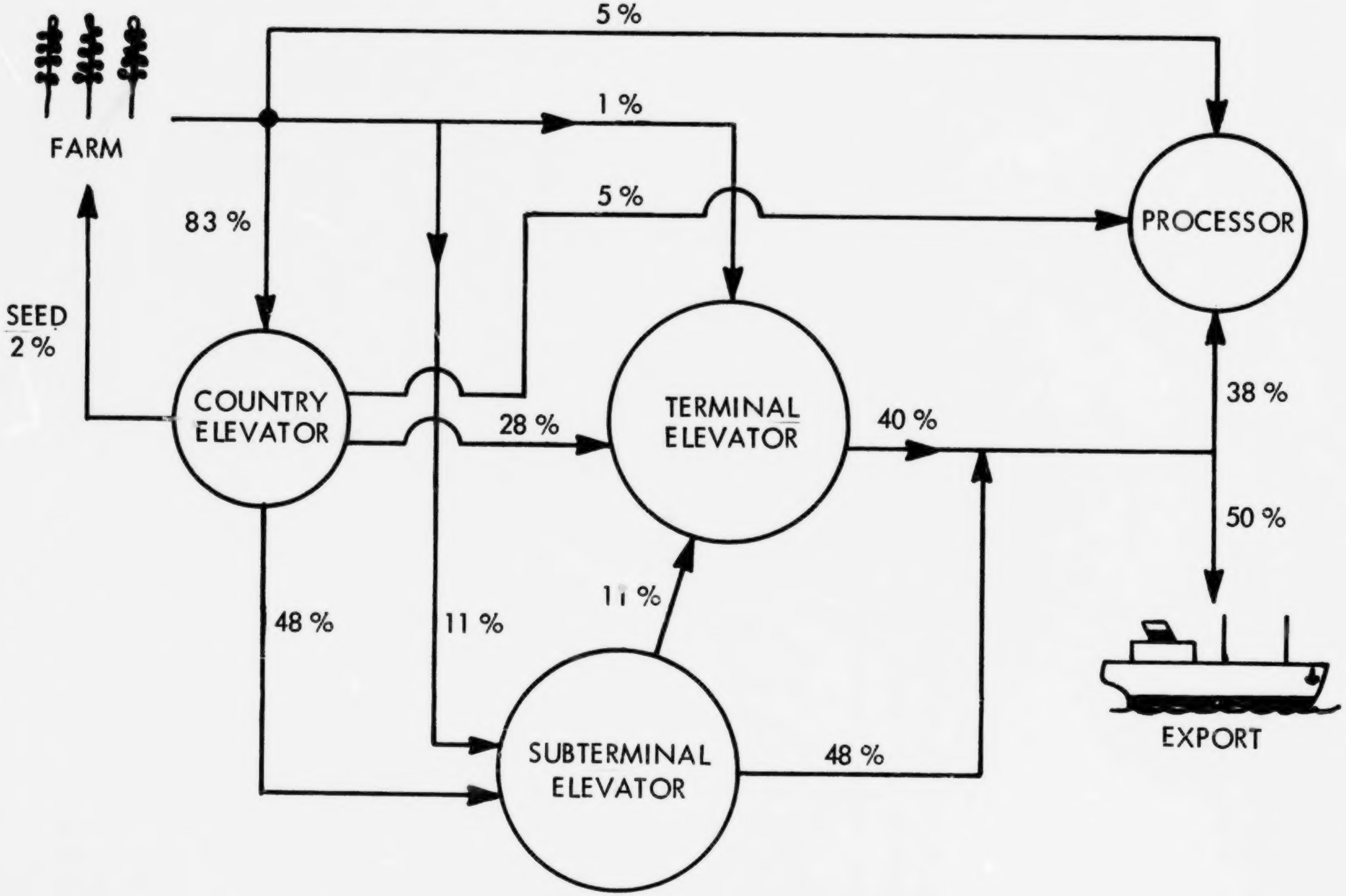
[a] Soybeans included.

[b] "For use as grain" is distinguished from use as sileage and forage.

Grain sold from farms goes to at least one elevator, but only a small percent goes directly to a processor's elevator (flour mill, cereal manufacturer, etc.). Figure 4.4-1 shows the movement of wheat from farm to market. Actually, approximately 20% of wheat shipped in any one year will be wheat already stored in an elevator from previous harvests. Similarly, 20% of a harvest will still be in storage at the time of the next harvest. Approximately 80% of a harvest goes to a country elevator, and less than 10% of this goes on to a processor's elevator without an intermediate stop in a terminal or a sub-terminal elevator. If, while grain is enroute, a shipper avails himself of "transit privileges," i.e., storage, cleaning, blending, even milling, a shipment may be "in transit for a year or more and may be stopped as many as three times for storage and processing."[8]



Adapted from "Agricultural Markets in Change," U. S. Department of Agriculture.7/

Figure 4.4-1 - Flow of Wheat from Farm to Market

To calculate the amount of dust generated in the transportation of grain, the assumption is made that the movement of all grain parallels that of the wheat movement shown in Figure 4.4-1 and that it passes through three elevators,--a country elevator, a terminal elevator, and a processor's elevator or a port elevator for export. The dust from loading, unloading, and conveying to and from storage is calculated as follows:

	Lb. Dust per Ton of Grain Handled	
Unloading		
from farm at country elevator	5	
at two other elevators	2	
		7
Transferring and conveying		
country elevator	3	
two other elevators	4	
		7
Loading		
at country elevator	5	
at one other elevator	1	
		6
Total dust from transporting grain from farm to market		20

Then

$$E = 177{,}000{,}000 \text{ tons grain} \times \frac{20 \text{ lb. dust}}{\text{ton grain}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} =$$

1,777,000 tons of dust per year generated in transport of grain from farm to processor's elevator or to a port elevator for export

The dust from cleaning is estimated by assuming that all grain is cleaned once.

$$E = 177{,}000{,}000 \text{ tons grain} \times \frac{6 \text{ lb. dust}}{\text{ton grain}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 531{,}000 \text{ tons}$$

of dust from cleaning grain

The dust from drying is estimated on the basis of data from an industrial source which indicated that the amount of grain dried in a terminal elevator is approximately 20% of the amount handled in a year's time.[16] Drying is done also in country elevators. Assuming that this percentage of grain is dried only one time, the dust generated by drying is estimated as follows:

$$E = (177{,}000{,}000 \times 0.20) \text{ tons grain dried} \times \frac{6 \text{ lb. dust}}{\text{ton grain}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}}$$

E = 106,000 tons of dust per year from grain drying.

The estimate of total dust generated from grain elevators in 1968 is:

Shipping and Receiving	1,777,000 tons
Cleaning	531,000
Drying	106,000
Total dust generated	2,414,000

Dust discharged to the atmosphere is estimated as follows:

C_c = 70%, average collection efficiency of dust collectors installed on grain elevators

C_t = 40%, percent of handling capacity of elevators on which dust collectors are installed

E = (2,414,000)(1-0.70 x 0.40) = 1,700,000 tons of dust discharged to the atmosphere from grain elevators in 1968

4.4.3 Cotton Ginning

Cotton ginning is primarily a process of separating seed from fiber; but it also involves the cleaning of raw cotton which, as brought to the gin from the field, contains leaves and stems from the cotton plants as well as dirt, stones, sticks, etc. The following units in a ginning plant may be equipped with exhaust systems.[9,10]

1. Trailer unloading
2. No. 1 dryer (full tower)
3. No. 2 dryer (stub tower)
4. Cylinder cleaners
5. Stick and green-leaf machine
6. Extractor feeder
7. Gin stand
8. Lint cleaner
9. Condenser

Ducting arrangements vary widely in hooking up exhaust systems for these units.

Emission factors are based on data in Reference 10, the report on air pollution from cotton gins by the Taft Sanitary Engineering Center. Table 4.4-3 shows a derivation of factors on a basis of lb/bale. The left-hand column, "% by Wt. of Cotton Ginned," is the same, with the percentages rounded, as the column headed "Total (T)" in Table 2, "Effluent Summary" in the Taft report. The second column, "Lb/Ton of Cotton Ginned," is derived directly from the left-hand column. The factors listed in the right-hand column, "Lb/Bale," are obtained by calculating fractions of the total emission factor, 12 lb/bale, which is obtained from Table 3, "Atmospheric Particle Emissions," in the Taft report. The factor listed there for "Total Discharge, No Control" is 11.7 lb/bale. The fractions are obtained from the second column. For example, the emission factor of 5 lb/bale for unloading fans is obtained as 20/50, or 2/5, of 12.

TABLE 4.4-3

ESTIMATE OF EMISSION FACTORS FOR COTTON GINNING

Source	% by Wt. of Cotton Ginned	Lb/Ton of Cotton Ginned	Lb/Bale[a]
Unloading Fan	1	20	5
Six Cylinder Cleaner	0.2	4	2 (incl. 7 cyl.)
Stick and Bur Machine plus Huller Front and Mote Discharge Stand	0.7	14	3
Separator No. 2	0.1	2	-
Seven Cylinder Cleaner	0.3	6	
Separator No. 3 (Lint Cleaner)	0.1	2	1
Condenser	0.1	2	1
Total Discharge to the Atmosphere		50	12

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[a] 500 lb/bale

The amount of particulate emissions which might be expected to settle on the plant premises was measured in the Taft project by including in the sampling train a settling chamber which was designed to collect particles of 100 μ and larger--a size large enough to settle rapidly. The amount of particulate collected in the settling chamber was approximately 40% of the total discharge. The amount of "air pollution material" is thus measured as 7 lb. of particulate per bale of cotton ginned.

Estimation of the amount of material discharged to the atmosphere from cotton gins is as follows:

P = 11,000,000 bales of cotton ginned in 1968
e_f = 12 lb. particulate per bale of cotton ginned
C_c = 80%, average collection efficiency of cyclones in use in the industry
C_t = 40%, percent of production capacity of the various processing units in cotton gins on which cyclones are installed

$$E = \frac{(11{,}000{,}000)(12)(1-0.80 \times 0.40)}{2{,}000} = 45{,}000 \text{ tons of particulate discharged to the atmosphere}$$

If 40% of the particulate discharged to the atmosphere settles on plant premises, the air pollution from cotton gins would be estimated as 60% of 45,000, or 27,000 tons of particulate air pollution from cotton gins in 1968.

4.4.4 Alfalfa Dehydrators

Air pollution from alfalfa dehydrating plants comes from cyclones which function as collectors of the alfalfa at various points in the process rather than as auxiliary dust control equipment. Transport of material is by pneumatic conveying. Although a variety of equipment layouts and duct systems exists among alfalfa dehydrators, cyclones are located at four points in a typical plant design. Their location and functions are listed as follows:

1. Primary cooling cyclone--This cyclone is located at the discharge from the dryer and acts as a cooler. "Heavy trash" is separated from the dried hay in this cyclone.

2. Secondary cooling cyclone--This cyclone is in series with the first. It effects further cooling and acts as a hopper for the mill.

3. Air-meal separator--This cyclone collects ground alfalfa meal.

4. Pellet-meal separator--This cyclone handles air used to cool pellets, which are made by extrusion with steam. Meal dust which has passed through the pellet machine and fragments of pellets are separated from the air stream.

In mills which manufacture formula feeds by blending alfalfa with other ingredients, a fifth source is the pellet-regrind cyclone. This cyclone separates powder from re-ground pellets from the air stream conveying the powder to a blender.

Emission factors for alfalfa dehydrators were obtained from two sources. Reference 12 lists results obtained in plants in Kansas and Ohio. Data were also made available on tests conducted in 1969 by the American Dehydrators Association.[13] Table 4.4-4 lists emission factors derived from information on three plants in Reference 12.

TABLE 4.4-4

EMISSION FACTORS FOR ALFALFA DEHYDRATORS[12]

Source	Emission Factor (lb/ton of dry meal)
1. Primary cooling cyclone	11
2. Secondary cooling cyclone	4
3. Air-meal separator	
a. Cyclone	47
b. Cyclone + skimmer[a]	9
4. Pellet-meal separator	2
5. Pellet re-grinder	2

---

[a] Skimmer is a device for skimming off the peripheral flow in a cyclone and conducting the skimmed flow to a secondary collector.

The data from the trade association[13] indicate an average of approximately 8 lb. of dust per ton discharged to the atmosphere from an entire plant. The average is for eight plants; the range is 3-19 lb/ton of dry meal.

Calculation of particulate emissions from alfalfa dehydrators involves selection of an average emission factor from the above data and estimation of the extent and effectiveness of dust control equipment installed. High-efficiency cyclones and multi-tube cyclones have been installed in some plants. Reference 12 describes a baghouse installation in Ohio which is said to be satisfactory with "alert and careful operation." Two plants in Kansas use baghouses. The use of vegetable oil and animal fat, injected into the process stream at the grinding of the dehydrated hay, has reduced dust. A scrubbing process which utilizes moist air from the dehydrator is a recent development which has been found satisfactory. Of the factors listed in Table 4.4-4, the most typical value is 64 lb/ton of dry meal which is the total of sources 1, 2, 3a and 4.

Of the plants in the data furnished by the American Dehydrator Association, several have installed the wet scrubbing system referred to above. The average for this group is thus somewhat lower; however, the upper limit of the range is much less than the factor of 64 lb/ton obtained from Reference 12. Reference 12 reports "loss to the atmosphere" to be between "1 and 3-1/2 wt. % of the dry meal production" in the plants sampled. This is a range of 20-70 lb/ton of dry meal produced. To estimate the dust from alfalfa dehydrators, an average emission factor of 50 lb/ton of dry meal was assumed. This factor was taken as an average of the total dust discharged from large-diameter cyclones. On the basis of information from projects presently being conducted by Midwest Research Institute,[17,18] it was assumed that plants totaling half of the production capacity of the industry have increased the efficiency of dust collection with some type of secondary equipment or replacement of large-diameter cyclones with installation of high-efficiency cyclones. The average operating efficiency of the additional equipment is assumed to be 85%. The estimate for particulate emissions is thus calculated as follows:

P = 1,582,400 tons of dehydrated alfalfa meal produced in 1968
e_f = 50 lb. dust discharged from large-diameter cyclones per ton of dry meal
C_c = 85% average collection efficiency of additional dust collection equipment installed
C_t = 50% of production capacity of the industry on which additional dust collection equipment has been installed

$$E = \frac{(1,580,000)(50)(1-0.85 \times 0.50)}{2,000} = 23,000$$

tons of dust discharged to the atmosphere from alfalfa dehydrators in 1968

4.4.5 Feed Mills Other Than Alfalfa Mills

Included under this heading are estimates of particulate emissions for milled feeds for which no information on particulate emissions was obtained. The estimates are based on an assumed emission rate of 1% of the product. Dust collection in these mills is assumed to be equivalent to dust collection in alfalfa mills. Production listed in Table 4.4-1 are for 1967.[19]

4.4.6 Flour Mills

Particulate emissions from flour mills come mainly from the loading of waste products, chaff and middlings, into railroad cars. The product, flour, is a powder; however, because of its value, the collection is well controlled.[15] No estimate was made of the dust from loading of waste product.

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16. Private communication, industrial source.

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4.5 Iron and Steel

Sources of particulate emissions in the iron and steel industry are outlined as follows.

A. Ore Crushing
B. Pellet Plants
C. Sinter Plants
D. Coke Manufacture
E. Blast Furnaces
F. Steel Furnaces
  1. Open hearth
    a. No oxygen lancing
    b. Oxygen lancing
  2. Basic oxygen furnace (BOF)
  3. Electric arc
G. Scarfing
H. Materials Handling--includes soaking pits, pickling lines, etc.

A summary of emission factors and the emissions calculated are shown in Table 4.5-1. Data on emission factors were found for sinter plants, the various furnaces used in the industry and scarfing machines. The emission factor used for by-product ovens is an estimate. The factors listed for coke pushing and for quenching towers are from a single source. Emission factors for ore crushing and materials handling were derived from data on similar operations in other industries. Emissions data for pellet plants or for the various parts of furnace production cycles, i.e., charge, heat and tap, were not found or did not give production rates with which factors could be calculated on a process-weight basis. Values of C_c and C_t used in the calculations are discussed in Chapter 5, pp. 220-222.

Production data and data for quantities of raw materials were obtained from the 1968 Minerals Yearbook, Vol. I-II.

4.5.1 Ore Crushing

Ore crushing is generally done at mine sites before transporting it to the steel mills. The fineness to which ores are ground depends upon the iron content. Ore mined in this country now must be upgraded. This can be done with some ores by merely crushing, screening, and washing. Ores which are beneficiated by magnetic separation, such as the magnetic taconites which are now a major portion of ore mined in the United States, are milled to a fineness of 200 mesh. Ores used for making pellets must be ground to -200 mesh.1/

TABLE 4.5-1

PARTICULATE EMISSIONS IRON AND STEEL INDUSTRY

	Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control C_c C_t	Emissions (tons/yr)
I.	Ore Crushing	82,000,000 tons of iron ore	2 lb/ton of ore	0.0	0.0	0.0	82,000
II.	Materials Handling	131,000,000 tons of steel	10 lb/ton of steel	0.90	0.35	0.32	446,000
	A. Loading-Unloading, Freight Cars, Barges, Ore Boats		-				
	1. Ore and ore fines		-	-	-	-	-
	2. Clay (bentonite)		-	-	-	-	-
	3. Limestone		-	-	-	-	-
	4. Coal		-	-	-	-	-
	5. Scrap metal		-			-	
	B. Conveyors						
	1. Transfer points		-	-	-	-	-
	2. Discharge to bins stockpiles		-	-	-	-	-
	C. Elevators						
	1. Boots		-	-	-	-	-
	2. Heads		-	-	-	-	-
III.	Pellet Plant	50,000,000 tons of pellets					80,000
	A. Grate Feeder		-	-	-	-	-
	B. Dryer		-	-	-	-	-
	C. Kiln		-	-	-	-	-
IV.	Sinter Plant	51,000,000 tons of sinter					
	A. Sintering Process		20 lb/ton sinter	0.90	1.0	0.90	51,000
	B. Crushing, Screening, Cooling		22 lb/ton sinter	0.90	1.0	0.90	56,000
V.	Coke Manufacture						
	A. Ovens						
	1. Beehive	775,000 tons of coke - 1,300,000 tons of coal	200 lb/ton of coal	0.00	0.00	0.00	130,000
	a. Charging		-	-	-	-	-
	b. Coking		-	-	-	-	-
	c. Pushing		0.08 lb/ton of coal	-	-	-	-
	2. By-Product	63,700,000 tons of coke - 90,000,000 tons of coal	2 lb/ton of coal	0.00	0.00	0.00	90,000
	a. Charging		-	-	-	-	-
	b. Coking		-	-	-	-	-
	c. Pushing		0.08 lb/ton of coal[a]	-	-	-	4,000
	B. Quenching Tower		0.38 lb/ton of coal[a]	-	-	-	17,000
	C. Grinder		-	-	-	-	-
	D. Screen		-	-	-	-	-
	E. By-Product Recovery Plant		-	-	-	-	-

TABLE 4.5-1 (concluded)

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/year)
VI. Blast Furnaces	88,800,00 tons of pig iron					
A. Charge		-	-	-	-	-
B. Heat		-	-	-	-	-
C. Tap		-	-	-	-	-
		130 lb/ton of pig iron	0.99	1.00	0.99	58,000
VII. Steel Furnaces						
A. Open Hearth	65,800,000 tons of steel					
1. No oxygen lancing						
a. Charge		-	-	-	-	-
b. Heat		-	-	-	-	-
c. Tap		-	-	-	-	-
		8 lb/ton of steel	-	-	-	-
2. Oxygen lancing						
a. Charge		-	-	-	-	-
b. Heat		-	-	-	-	-
c. Tap		-	-	-	-	-
		21 lb/ton of steel	-	-	-	-
	Average for open hearth	17 lb/ton of steel[b]	0.97	0.41	0.40	337,000
B. Basic Oxygen (BOF)	48,000,000 tons of steel					
1. Charge		-	-	-	-	-
2. Heat		-	-	-	-	-
3. Tap		-	-	-	-	-
		40 lb/ton of steel	0.99	1.00	0.99	10,000
C. Electric Arc	16,800,000 tons of steel					
1. Charge		-	-	-	-	-
2. Heat		-	-	-	-	-
3. Tap		-	-	-	-	-
		10 lb/ton of steel	0.99	0.79	0.78	18,000
VIII. Scarfing	131,000,000 tons of steel	3 lb/ton scarfed	0.90	0.75	0.68	63,000
IX. Pickling		-	-	-	-	-
		Total for Iron and Steel				1,442,000

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[a] Industrial source.

[b] Emission factor is assumed to be an average for the total heat cycle.

Estimate of the particulate emissions from ore crushing are based on the emission factors for rock crushing in the crushed stone industry. The factor used here is the sum of the factors for primary and secondary crushing, 2 lb/ton of material crushed. The tons of dust from ore crushing are estimated as follows.

$$E = 82{,}000{,}000 \text{ tons ore} \times \frac{2 \text{ lb. dust}}{\text{ton ore}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 82{,}000 \text{ tons}$$

4.5.2 Pellet Plants

Production of "agglomerates" in 1968 was 50,000,000 tons. Data on particulate emissions from pellet plants are lacking; but if an emission rate of 25 lb. of particulate per ton of pellets produced and collection of three fourths of the dust generated be assumed for pellet plants, the quantity of dust discharged to the atmosphere would be approximately 80,000 tons.

4.5.3 Sinter Plants

There are two sources of dust in sintering operations. The first is the moving grate on which the ore and coke is sintered. The air pulled through the material on the grate entrains dust. The second source is collectively the crushing, screening and cooling of the sinter. The emission factors for these two sources are:[2]

Sintering process	20 lb/ton sinter
Crushing, screening, cooling	22 lb/ton sinter

The emissions from the sintering process are calculated as follows.

$$E = (51{,}000{,}000) \left(\frac{20}{2{,}000}\right) (1\text{-}1.0 \times 0.90) = 51{,}000 \text{ tons}$$

The emissions from crushing, screening and cooling are calculated as follows.

$$E = (51{,}000{,}000) \left(\frac{22}{2{,}000}\right) (1\text{-}1.0 \times 0.90) = 56{,}000 \text{ tons}$$

The total quantity of emissions from sintering plants is thus estimated at 107,000 tons.

4.5.4 Coke Manufacture

Emissions from coke ovens occur during charging of the raw material and pushing (removal of finished coke) as well as during the process. The particulate emissions generated during the process, the heating of the coal, can be estimated at approximately 200 lb/ton of coal consumed on the basis of material balances. The following tabulation shows approximate amounts of the products obtained from one ton of coal in the manufacture of coke.[4]

Coke	1,400 lb.
Coke breeze	70-100 lb.
Tar	10 gal.
Ammonium sulfate	20 lb.
Light oil	3 gal.
Gas	11,000 cu. ft.

If the weight of the oil and tar is assumed to be 6.5 lb/gal, the amount of products that might be discharged from the oven as particulate matter can be estimated as follows.

Coke breeze	85 lb.
Tar	65 lb.
Light oil	20 lb.
Total as particulate	170 lb.

The ammonium sulfate is formed by absorbing ammonia from the oven in sulfuric acid.

Quenching is also a source of pollution. The spraying of hot coke with water results in the formation of steam which carries off particulate matter. An estimate of the emissions is given in Table 4.5-1.

The amount of particulate discharged to the atmosphere depends on the extent to which the by-products are recovered. Beehive ovens discharge all the by-products to the atmosphere. The effluent from slot ovens, or "by-product" ovens, can be processed for by-product recovery; and the air pollution can be substantially reduced. However, the extent to which by-products are recovered may be a function of economic factors. The development of the synthetic organic chemicals industry has depressed the market for by-products from coke ovens; consequently, the economic motivation to collect the by-products has decreased.

The emission factors used for coke ovens are:

Beehive ovens	200 lb/ton coal
Slot (by-product) ovens	2 lb/ton coal[5]

The particulate pollution from each type is estimated as follows.

Beehive

$$1{,}300{,}000 \text{ tons coal} \times \frac{200 \text{ lb. particulate}}{\text{ton of coal}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 130{,}000 \text{ tons}$$

Slot ovens

$$90{,}000{,}000 \text{ tons coal} \times \frac{2 \text{ lb. particulate}}{\text{ton of coal}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 90{,}000 \text{ tons}$$

These estimates show that, although coke production from beehive ovens is only about 1% of the total production, the particulate pollution from beehive ovens is over half the total particulate pollution from coke ovens.

4.5.5 Blast Furnaces

Particulate matter from furnaces is composed of fume, kish, and dust from the raw materials. Kish is the carbon particles which solidify from the molten metal when it is cooled during the tap or, in BOF furnaces, when cold scrap is dumped into molten metal during the charge. Kish floats to the molten surface and is swept off by drafts created by the high temperature of the molten metal. Dust from raw materials arises during charging. Fume is discharged during the heat.

The blast furnace is the first step in steel manufacture. In the blast furnace, iron is separated from its matrix to produce pig iron. Particulate emissions from blast furnaces depend on the proportions of sinter and pellets in the burden. A burden in which the iron ore is charged as pellets and sinter produces approximately 10% of the particulate emissions produced from burdens of lump ore. "The addition of 3,000 lb. of sinter plus pellets/net ton of hot metal can decrease the dust from 300 to 30 lb/net ton of hot metal."[3] Data published in 1963 give an emission factor of 0.1 ton of dust/ton of pig iron produced.[6] Data published in 1969 indicate that the proportion of pellets and sinter in the burden of blast furnaces is increasing steadily from year to year.[7] It might be expected, therefore, that an average emission factor for particulate matter from blast furnaces would be decreasing. On the basis of these statements, the emission factor for blast furnaces is selected as 130 lb/ton of pig iron produced. The quantity of particulate emissions from blast furnaces is estimated as follows.

$$E = 88{,}800{,}000 \text{ tons pig iron} \times \frac{130 \text{ lb. dust}}{\text{ton pig iron}} \times (1-1.0 \times 0.99) =$$

58,000 tons

4.5.6 Steel Furnaces

The most important furnaces for making steel currently in use in the United States are (1) the open hearth, (2) the basic oxygen furnace, and (3) the electric-arc. The open hearth furnace is the oldest. It is being succeeded by the basic oxygen furnace, which has a much higher production rate. The electric-arc furnace is adaptable to close temperature control, and its primary use has been in making alloy and stainless steels. However, in the past decade, it has become an increasingly important producer of carbon steel.

4.5.6.1 Open Hearth Furnaces: The rate of emissions of particulate matter from open hearth furnaces is affected by the use of oxygen lancing. Oxygen lancing shortens the length of time required for a heat and decreases fuel consumption. This practice is widely used in open hearth operations. The following emission factors are listed for open hearth furnaces.8/

Without oxygen lancing	8 lb/ton of steel
With oxygen lancing	21 lb/ton of steel

A factor of 17 lb/ton has been estimated as a weighted average for these two factors.9/ This factor is used to estimate the quantity of particulate emissions from open hearth furnaces.

$$E = (65{,}800{,}000) \left(\frac{17}{2{,}000}\right) (1-0.97 \times 0.41) = 337{,}000 \text{ tons}$$

4.5.6.2 Basic Oxygen Furnace (BOF): The basic oxygen furnace uses oxygen lancing as an integral part of the process and is designed to facilitate the use of lances. The emission factor used to estimate the particulate emissions from basic oxygen furnaces is 40 lb. particulate/ton of steel produced.10/ Estimate of the quantity of emissions from basic oxygen furnaces is as follows.

$$E = (48{,}000{,}000) \left(\frac{40}{2{,}000}\right) (1.0-1.0 \times 0.99) = 10{,}000 \text{ tons}$$

4.5.6.3 Electric-Arc Furnaces: The rate of particulate emissions from electric-arc furnaces is the lowest of the three kinds of steel furnaces considered here. Since scrap metal is the usual charge to these furnaces, dirty scrap is a frequent source of particulate emissions. The emission factor used is 10 lb. per "ton of metal;" this basis is assumed to be metal melted.10/ Since the charge is scrap, this value is assumed for a basis of tons of steel produced. The quantity of particulate emissions from electric-arc furnaces is estimated as follows.

$$E = (16{,}800{,}000) \left(\frac{10}{2{,}000}\right) (1-0.99 \times 0.79) = 18{,}000 \text{ tons}$$

4.5.7 Scarfing

Scarfing is the term applied to the process of removing blemishes from the solid shapes (billets, blooms, slabs) into which molten steel is formed. The emission factor used to estimate the particulate emissions from scarfing is 3 lb/ton of steel.[5] In calculating the estimate, it is assumed that all steel is scarfed.

$$E = (131{,}000{,}000)\left(\frac{3}{2{,}000}\right)(1-0.90 \times 0.75) = 63{,}000 \text{ tons}$$

4.5.8 Materials Handling

The emission factor used to estimate dust from materials handling is based on the factor for materials handling in the crushed stone industry. For materials handling, a factor of 1.7 lb. per ton has been reported.[11] Included in the operations for this factor are "general screening, conveying, and handling." For stone crushing this factor pertains to one commodity. In using this factor for materials handling in the iron and steel industry, account is to be taken of the fact that several materials are handled. Ore, coal, and limestone are handled in large quantities. Also desirable would be a comparison of the number of sources--elevators, conveyor transfer points, screens, stockpiles, etc., existent in the flow of materials in the production of steel to the number of these sources in a rock-crushing plant.

To estimate the amount of dust arising from materials handling, an emission factor, considered conservative, of 10 lb/ton of finished steel is used.

$$E = (131{,}000{,}000)\left(\frac{10}{2{,}000}\right)(1-0.90 \times 0.35) = 446{,}000 \text{ tons}$$

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4.6 Cement Plants

In the manufacture of cement the most important source of air pollution is the calcining kiln, and most of the sampling in cement plants has been the measurement of dust emissions from kilns. There are, however, other significant sources of dust in cement plants. These include mills, driers, elevators, and hoppers.

The emission factor for the kilns was calculated from data in the U.S. Public Health Service Publication, AP-17, "Atmospheric Emissions from the Manufacture of Portland Cement,"[1] and data obtained from air pollution control agencies in several states; a collective emission factor for mills, driers, elevators, and hoppers was derived as described later in the chapter. Most of the data from state agencies do not contain any stack sampling tests upstream from dust collectors. To calculate emission factors and estimate the particulate emissions from cement manufacturing, a statistical analysis was made of the data in Reference 1 to ascertain differences between dust loads from kilns of the two processes, wet and dry, indicated by these data. Table 4.6-1 shows an array of the emission factors calculated for each plant for which sufficient data were listed in Tables 4 and 5 of the reference and the calculations for the statistical test of the difference between the means.

The "t" test indicates that the difference between the average emission factors is not statistically significant. Therefore, a single emission factor was used for both wet and dry process cement kilns. Emission factors and estimated emissions are summarized in Table 4.6-1.

The average emission factor for dust discharged from kilns is 245 lb. dust/ton of cement produced. This value is an arithmetic average of 31 items of data. The geometric mean of these data is 167 lb/ton. The median is 190 lb/ton; the range is 13-715 lb/ton. Table 4.6-2 is a tabulation of the statistics calculated from the data at hand.

The arithmetic mean for emissions from control equipment is 10.5 lb. dust/ton of cement produced; the geometric mean is 3.8 lb/ton. The range of emissions from control equipment is 0.19 - 69 lb/ton; the upper extreme is 363 times the lower extreme. A classification of the data for emissions from control equipment is given below. Included in these data are 25 tests made by stack sampling teams from state air pollution control agencies and 28 tests in Reference 1.

No. of values less than 1.0 lb. partic. per ton of cement	10
No. of values from 1.0 to 3.0	17
No. of values from 3.0 to 10	15
No. of values from 10 to 30	9
No. of values from 30 to 50	4
No. of values above 50	2

TABLE 4.6-1

COMPARISON OF EMISSION FACTORS FOR CEMENT KILNS

	Dry Process (lb. dust/ton cement)	Wet Process (lb. dust/ton cement)
	13	35
	83	80
	93	96
	203	107
	214	146
	231	149
	332	178
	364	192
	556	228
		277
		363
		437
		628
Avg. Emission Factor	232 $\frac{\text{lb. dust}}{\text{ton cement}}$	224 $\frac{\text{lb. dust}}{\text{ton cement}}$
Std. Deviation	167	166
Std. Error	55.6	46.1

Hypothesis: There is no difference between the average emission factors.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{s^2 \frac{N_1 + N_2}{N_1 N_2}}}$$

$$s^2 = \frac{(N_1-1)s_1^2 + (N_2-1)s_2^2}{N_1 + N_2}$$

$$s^2 = \frac{(9-1)(55.6)^2 + (13-1)(46.1)^2}{13 + 9} = 2{,}511.67$$

$$t = \frac{232-224}{\sqrt{2{,}511.67 \ \frac{13+9}{13 \times 9}}} = \frac{8}{21.7} = 0.368$$

degrees of freedom = 13 + 9 - 2 = 20

$t_{0.50}$ level of probability = 0.687

Formulas from Walker and Lev, Statistical Inference, Henry Holt and Co., New York, 1953, p. 156.

TABLE 4.6-2

STATISTICAL CALCULATIONS-EMISSIONS FROM CEMENT KILNS

	Dust Discharged from Kilns	Emissions from Control Equipment
Arithmetic Mean, M_a	245 lb/ton	10.5 lb/ton
Geometric Mean, M_g	167 lb/ton	3.8 lb/ton
Median	190 lb/ton	3.6 lb/ton
Range	13 - 715 lb/ton	0.19 - 69 lb/ton
Number of Samples , N	30	57
Standard Deviation, S	193	15.8
Standard Error of the Mean, S_M	35.3	2.1
Coefficient of Variation S/M	0.79	1.5

The statistics show the influence of a comparatively few large sampling results. Note in particular that for emissions from control equipment the standard deviation is larger than the mean. Some explanation other than wide variation of amounts of particulate pollutants being intrinsic to industrial processes should be sought. One consideration is that much of the data on emissions from control equipment come from plants in areas where intensive effort is being made to control air pollution. The lowest rates for controlled emissions (0.19, 0.27, 0.35 lb/ton) may be assumed to be from plants with effective dust collectors in good operating condition. Type of fuel may also be a factor. Values for four plants in which coal was reported as the fuel for heating the kilns are 63, 28, 18 and 1.5 lb. particulate/ton of cement produced. Thus, coal may contribute to a high emission rate; however, the lowest of these four values indicates that a low emission rate is possible with coal-fired kilns. Type of kiln and manner of operation can exert a strong effect on emission levels.

The total amount of emissions presently discharged from cement kilns is estimated by using the source emission factor for dust discharged from kilns and estimates of the effectiveness of dust collection equipment currently being used. Because of the considerable dispersion of the data, the geometric mean may give a more realistic value than the arithmetic mean, and it was therefore used in calculating the estimate of total emissions.

$$E = \frac{Pe_f(1-C_cC_t)}{2{,}000}$$

P = 43,600,000 tons cement-wet process
$\underline{31{,}000{,}000}$ tons cement-dry process
74,600,000 tons, cement produced in 1968
e_f = 166 lb. partic/ton cement
C_c = 94%, average operating efficiency of dust collectors on cement kilns
C_t = 94%, percentage of kiln capacity for which dust collectors are installed

$$E = \frac{(74{,}600{,}000)(167)(1-0.94 \times 0.94)}{2{,}000} = 745{,}000 \text{ tons of particulate}$$

discharged to the atmosphere in 1968 from cement kilns.

If the total industry had the effectiveness of control indicated by the data obtained for emissions from control equipment (an unrealistic assumption), dust discharged to the atmosphere from kilns would be estimated as follows. The geometric mean is used to calculate the estimate.

$$E = \frac{74{,}600{,}000 \text{ tons cement}}{\text{yr.}} \times \frac{3.8 \text{ lb. partic.}}{\text{ton cement}} \times \frac{1 \text{ lb.}}{2{,}000 \text{ tons}} = 141{,}000 \text{ tons}$$

As mentioned above, there are significant sources of dust in cement plants in addition to kilns. In dry-process plants the grinding and drying of the raw materials generates much dust. Finish grinding of the product is a dust source in both types of plants. Handling and transfer of material and bagging machines also generate dust. One report[2/] mentions 3,390 lb. of dust/hr collected from "dryers, mills, elevators and hoppers." Dust from the kilns was measured at 8,397 lb/hr. These two values were obtained four days apart; but if it be assumed that production rate was approximately the same over that time, the dust discharged from other sources in the plant was approximately 40% of that discharged from the kilns. In a wet-process plant, there would be much less dust from the preparation of raw materials. In the wet process, water is added to the raw materials as they are ground; and they are handled as a slurry from grinding to the kilns. In the dry process, the raw materials are ground while dry, and a heated air stream is used to separate fines from oversize in the material discharged from the grinder. The dry fines are conveyed to the kiln; the oversize is returned to the grinder. Fifteen percent is the estimate of the percentage of dust from other plant sources in a wet process plant compared to the dust being discharged from the kiln.

An emission factor for dryers, mills, elevators, etc. is calculated from the kiln emission factor as follows.

Dry-process plants: 167 x 0.40 = 67 lb. particulate/ton of cement
Wet-process plants: 167 x 0.15 = 25 lb. particulate/ton of cement

Total emissions from these secondary sources were calculated with the assumption that the average operating efficiency (C_c) and percentage of production capacity controlled (C_t) were the same as for kilns. Information obtained from personnel in this industry indicates that this assumption is suitable. (See Table 4.6-3.)

TABLE 4.6-3

PARTICULATE EMISSIONS
CEMENT MANUFACTURE

Source	Production	Emission Factor e_f	Efficiency of Control C_c	Application of Control C_t	Net Control $(C_c \cdot C_t)$	Emissions (tons/yr)
Kilns	74,600,000	167	0.94	0.94	0.88	745,000
Grinders, Dryers, Elevators, etc.						
Wet Process	43,600,000	25	0.94	0.94	0.88	65,000
Dry Process	31,000,000	67	0.94	0.94	0.88	124,000
				Total for Cement		934,000

REFERENCES

CEMENT

1. Kreichelt, T. E., Douglas A. Kemnitz and S. T. Cuffe, "Atmospheric Emissions from the Manufacture of Portland Cement," U. S. Public Health Service Publication No. 999 AP-17, 1967.

2. Cuffe, Stanley T., "Report on the Air Pollution Aspects of the Universal Atlas Cement Division of United States Steel Corporation at Duluth, Minnesota," Technical Assistance Branch, Division of Air Pollution, U. S. Public Health Service, Cincinnati, Ohio, circa 1965.

4.7 Forest Products

Under the heading "Forest Products," the production of pulp for paper manufacturing is the most important source of particulate pollutants from plants in this industry. However, the burning of logging wastes, "slash" burning, which takes place in the forests, produces particulate matter in an amount much larger than that from pulp mills. The burning of waste from mills in wigwam burners is also an important source. Particulate pollutants in comparatively smaller amounts are produced in plywood manufacture and in manufacture of particleboard and hardboard. Particleboard and hardboard are made from waste and were developed partly from efforts to solve waste-disposal problems. Particulate pollution from sawmills is mostly from burning of waste. Pollution control agencies in states where lumber is an important industry have not found the sawing of lumber to be an important source of pollution.

A summary of emission factors and calculated emissions is shown in Table 4.7-1. The emission factors for the sources in pulp mills are obtained from the literature. No factor is listed in this table for bark boilers since the quantity of emissions was calculated without using an emission factor. The factors for plywood, particleboard and hardboard are derived as described later in the chapter. The estimate for quantity of emissions from slash burning is also calculated without using an emission factor. Values of C_c and C_t used in the calculations are discussed in Chapter 5, p. 223.

4.7.1 Slash Burning

Particulate emissions from slash burning have been estimated by two agencies of the U. S. Department of Agriculture. The Forest Service has ventured an estimate of 17,000,000 tons of particulate matter produced by "Prescribed Fires"[1] in the United States in 1967 with 6,000,000 tons of this ascribed to the western part of the country where burning is primarily to "reduce the flammability of heavy concentrations of slash left after timber cutting." This agency estimates that the "fuel consumed in the west" is 21,000,000 tons/year. The estimate of 6,000,000 tons of particulate matter is based on an estimate of the products of combustion from wood. An average chemical composition, $C_4H_{10}O_9$, was assumed; and estimates were made of the amounts of gases, solid matter, and condensed organic vapors that would be formed as combustion products. An inventory of quantities of slash burned was available. The inventories had been compiled by field representatives of the Forest Service who were familiar with burning activity. The Soil and Water Conservation Research Division estimates that 25,000,000 tons of logging debris are burned each year and that 6,500,000 tons of particulates are produced by "prescribed burning in the forests."[2]

TABLE 4.7-1

PARTICULATE EMISSIONS
FOREST PRODUCTS INDUSTRY

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emission (tons/yr)
I. Slash Burning	23,000,000 tons/yr					6,000,000
II. Wigwam Burners	27,500,000 tons/yr	10 lb/ton				132,000
III. Chemical Pulp Mills						
A. Kraft Process	24,300,000 tons pulp					
1. Recovery furnace		150 lb/ton	0.92	0.99	0.91	164,000
2. Lime kiln		45 lb/ton	0.95	0.99	0.94	33,000
3. Dissolving tanks		5 lb/ton	0.90	0.33	0.30	42,000
B. Sulfite Process						
1. Recovery Furnace	1/3 of 2,500,000 tons pulp	268 lb/ton	0.92	0.99	0.91	10,000
C. N.S.S.C. Process						
1. Recovery furnace	1/3 of 3,500,000 tons pulp	24 lb/ton	0.92	0.99	0.91	1,000
2. Fluid bed reactor	15% of 3,500,000 tons pulp	533 lb/ton	0.70	1.00	0.70	42,000
D. Bark Boilers	32,000,000 tons pulp					82,000
			Total from Chemical Pulp Mills			374,000
IV. Plywood, Particleboard Hardboard	1,500,000,000 sq. ft. plywood/yr					
A. Boilers		2.6 lb/ton burned				3,000
B. Cyclones		45 $\frac{\text{dry tons}}{\text{MM sq. ft., plywood}}$				67,000
C. Veneer Dryers		250 lb/MM sq. ft., plywood				4,000
						74,000
			Total for Forest Products Industry			6,580,000

4.7.2 Wigwam Burners (Teepee Burners)

The estimate for emissions from wigwam burners in the Forest Products industry is based on an emission factor of 10 lb. of particulate discharged per ton of material burned.[14] Reference 14 lists the following data on emission factors for the burning of wood waste in "Conical and Cylindrical Burners."

1 lb/ton of waste charged--properly maintained burner with adjustable underfire air supply and overfire air inlets.

10 lb/ton of waste charged--properly maintained burner with overfire air supply.

20 lb/ton of waste charged--improperly maintained burner.

Boubel[15] lists a factor of 11 lb/ton of waste charged in a report on particulate emissions from the burning of sawmill wastes. The factor of 10 lb/ton was selected as representative.

Waste from cutting of logs amounts to approximately 50% of the log. In areas where pulp mills are located, much of the waste can be used in pulp manufacture. In the past several years, processes for manufacturing by-products such as particleboard and hardboard have been developed to utilize wood waste. In the Mid-Willamette Valley in 1968, only 30% of the log was burned in wigwam burners.[12] The following data[13] and assumptions were used to estimate the particulate pollutants discharged from wigwam burners in the Forest Products Industry.

Domestic production:

saw logs	5,765,000,000 cu. ft.
veneer logs	1,130,000,000 cu. ft.
pulpwood	3,255,000,000 cu. ft.

Assume 50% of log is waste.
Assume no waste from debarking and chipping pulpwood.
Total volume contributing to waste = 6,895,000,000 cu. ft.
Assume average density of 32 lb/cu ft.

$6{,}895{,}000{,}000 \times 32 \times \frac{1}{2{,}000} \times 0.5 = 55{,}100{,}000$ tons of waste/year.

Assume that 40% of timber production is subject to only 30% burning of waste because of by-product manufacture. The proportion, 40%, is estimated from the proportion of the nation's timber production which comes from the northwest. In 1967, the Pacific states (Oregon, Washington, and California) accounted for 46.3% of the total.[17] 55,100,000 x 0.30 x 0.20 = 3,306,000 tons of waste burned in areas with extensive utilization of waste.

Assume 70% of waste burned in areas where waste is not utilized 55,100,000 x (1-0.40) x 0.70 = 23,100,000 tons of waste burned.

Total weight of waste burned in wigwam burners = 26,400,000 tons. 27,500,000 x 10 x $\frac{1}{2,000}$ = 132,000 tons/year particulate pollutants discharged to the atmosphere from wigwam burners.

4.7.3 Pulp Mills

Pulp is manufactured by two kinds of processes: mechanical and chemical. The production in 1968 by process was as follows:

1. Mechanical	5,900,000 tons
2. Chemical	
a. Kraft	24,300,000
b. Sulfite	2,500,000
c. Neut.-sulf.-semi-chem.	3,500,000
d. Dissolving	1,500,000
e. Soda	200,000
	32,000,000
Total pulp manufactured	37,900,000

The mechanical process is not a source of particulate pollution. It is a grinding process which is carried out under water to keep down the temperature. The chemical processes, principally the Kraft process, involve several operations from which particulate pollution arises.

Most of the work in developing emission factors for the chemical processes has been done on the Kraft process, which accounts for approximately 75% of chemical pulp production. The main sources of particulate emissions and the corresponding emission factors for the Kraft process are listed in Table 4.7-2.

TABLE 4.7-2

SOURCES OF PARTICULATE EMISSIONS
IN KRAFT PULP MILLS

Source	Emission Factor
Recovery Furnace	150 lb. particulate/ton pulp
Lime Kiln	45 lb. particulate/ton pulp
Dissolving Tank	5 lb. particulate/ton pulp
Bark Boilers	35 lb. particulate/ton pulp

Data on emissions from recovery furnaces have been found in the literature mostly as ranges without listing individual test results. Ranges are listed here.

50 - 194 lb. particulate/ton pulp[3/]
82 - 238 lb. particulate/ton pulp[4/]
90 - 200 lb. particulate/ton pulp[5/]
105 - 157 lb. particulate/ton pulp[6/]

Reference 3, published in 1936, lists 12 tests for which the average is 102 lb/ton. The data in Reference 4 are taken from flow sheets; six of eight emissions rates in these data are below 125 lb/ton. Reference 5 contains a statement to the effect that 150 lb. particulate/ton of pulp is an average. The data of Reference 5 are from stack sampling tests, and 150 lb. particulate/ton of air-dry pulp is the source emission factor that appears "best." Data furnished by state control agencies (seven items), which are emission rates from control equipment, range from 1.9 to 17.4 lb. particulate/ton of pulp; the average is 9 lb/ton. A new plant in California[7/] reports an emission rate from the recovery furnace of 1.3 lb/ton of pulp. This plant has an electrostatic precipitator followed by a wet scrubber.

Of the chemical processes other than the Kraft, only the sulfite and the neutral-sulfite-semi-chemical are considered to produce a significant amount of particulate pollutants. These processes account for approximately 20% of chemical pulp production. Recovery furnaces are the main sources of particulate pollution in these processes. Approximately half of these plants do not recover the chemicals used; the spent liquor is discharged to ponds, etc. One-third of the plants using the N.S.S.C. process are adjacent to Kraft plants and discharge their spent liquor to the Kraft recovery boilers. The emission rate attributable to liquor from N.S.S.C. plants is 24 lb/ton of air-dry, unbleached pulp.[4/] Fluid-bed equipment has been introduced into N.S.S.C. plants for recovery of chemicals, and approximately 15% of production from the N.S.S.C. process comes from plants utilizing this equipment as a recovery furnace. Data from a flow diagram (N.S.S.C. Flow Diagram No. 3)[4] show a "Fluidized Bed Reactor and Cyclone" with an in-flow of 888 lb. of solids and 1,452 lb. of water per ton of air-dry pulp. If the amount of dust carried out of the fluid-bed reactor is assumed to approximate the rate of dust emissions from similar equipment in the smelting of zinc, approximately 60% of the solids in the feed, an emission factor for the fluid-bed reactor is calculated as follows.

$$\frac{888 \text{ lb. solids}}{\text{ton of pulp}} \times \frac{0.6 \text{ lb. particulate}}{\text{lb. solids}} = \frac{533 \text{ lb. particulate}}{\text{ton pulp}}$$

Flow sheets[4] for the sulfite process show emission rates of 212 and 325 lb. of particulate per ton of air-dry pulp for plants accounting for approximately 20% of production. The average of these two values is 268 lb/ton, and this average is used to estimate the particulate emissions from sulfite furnaces.

Calculation of the emissions from Kraft recovery furnaces is as follows.

$$E = \frac{Pe_f\ (1-C_cC_t)}{2,000}$$

P = 24,300,000 tons/year, air-dry pulp[13]

e_f = 150 lb. particulate/ton of pulp

C_c = 92% average operating efficiency of pollution control equipment on recovery furnaces

C_t = 99%, percent of capacity of pulp production for which pollution control equipment is installed on recovery furnaces

$$E = \frac{(24,300,000)(150)(1-0.92 \times 0.99)}{2,000}$$

= 164,000 tons particulate/year discharged to the atmosphere from recovery furnaces

An emission factor for the controlled source may be calculated from the above equation as follows.

$e_f(1-C_c) = (150)(1-0.91) = 12.0$ lb. particulate discharged to the atmosphere per ton of air-dry pulp

This can be compared with the average value of 9 lb/ton from the control agency data--very reasonable agreement.

The estimates of the particulate emissions from sulfite and N.S.S.C. furnaces are as follows.

N.S.S.C. - proportion to Kraft furnaces

$$E = (1/3 \times 3,500,000)\left(\frac{24}{2,000}\right)(1-0.92 \times 0.99) = 1,260 \text{ tons}$$

N.S.S.C. - proportion to fluid-bed reactors
Assume that the cyclones on these units have a collection efficiency of 70%

$$E = (0.15 \times 3,500,000)\left(\frac{533}{2,000}\right)(1-0.70) = 42,000 \text{ tons}$$

Sulfite
Assume that collection of particulate from recovery furnaces in sulfite plants is equivalent to the same operation in Kraft plants

$$E = (2,500,000 \times 1/3)\left(\frac{268}{2,000}\right)(1-0.92 \times 0.99) = 9,700 \text{ tons}$$

Data on emissions from lime kilns are meager. The few values that have been found vary from 18.7[8] to 96[9] lb. dust discharged from the kiln per ton of air-dry pulp produced. Reference 4 lists a range of 20-65 lb/ton. Forty-five pounds/ton is taken as the best value. Calculation of the emissions from lime kilns is as follows.

P = 24,300,000 tons/year, air-dry Kraft pulp
e_f = 45 lb. particulate/ton of pulp
C_c = 95%, average operating efficiency of dust collectors on lime kilns
C_t = 99%, percent of capacity of pulp production for which dust collectors are installed on lime kilns

$$E = \frac{(24,300,000)(45)(1-0.95 \times 0.99)}{2,000}$$

= 33,000 tons particulate/year discharged to the atmosphere from lime kilns

The emission factor for the controlled source, calculated by the same method that was used to calculate the controlled emission factor for recovery furnaces, is 2.30 lb. lime dust discharged to the atmosphere/ton of air-dry pulp produced. Good agreement with this value is obtained from the following data[10] which are presented on lime kilns as representative of a mill having a capacity of 300 tons of pulp.

Fan Capacity	25,000 to 30,000 cfm at 400°F and 15 in. W.C.
Impingement Scrubbers	0.2 to 0.6 Gr/SCF
Venturi Scrubbers	0.05 to 0.2 Gr/SCF

With a dust load of 0.2 Gr/SCF, the following emission factor is calculated

$$0.2\ \frac{\text{gr.}}{\text{cu. ft.}} \times \frac{27{,}500\ \text{cu. ft.}}{\text{min.}} \times \frac{520^\circ\text{R}}{862^\circ\text{R}} \times \frac{1\ \text{lb.}}{7{,}000\ \text{gr.}} \times$$

$$\frac{1{,}440\ \text{min.}}{\text{day}} \times \frac{1\ \text{day}}{300\ \text{tons pulp}}$$

$$= 2.3\ \text{lb. lime dust/ton of pulp}$$

Two stack samples from state control agencies list data from which emission factors of 1.6 and 1.4 lb/ton are calculated. This is fair agreement considering that no information about type of control device was available.

Dissolving tanks have received less attention in Kraft mills than furnaces and kilns. One article[11] lists three stack sampling results: 17.2; 20.0; and 14.0 lb. particulate from the tank/ton of pulp produced. Reference 4 lists a range of 1-4 lb/ton and the Air Pollution Control Board in the State of Washington uses 5 lb/ton.[16] One finds a threefold difference between the average of the stack samples and the listed values. The factor, 5 lb/ton, is used to calculate the emissions.

P = 24,300,000 tons/year, air-dry pulp
e_f = 5 lb. particulate/ton of pulp
C_c = 90%, average efficiency of mist collectors installed on dissolving tanks
C_t = 33%, percent of pulp production capacity for which dissolving tanks are equipped with mist collectors

$$E = \frac{(24{,}300{,}000)(5)(1-0.90 \times 0.33)}{2{,}000}$$

= 42,000 tons particulate/year discharged to the atmosphere from dissolving tanks

The emissions from bark boilers are calculated from data obtained in a study which the National Air Pollution Control Administration conducted with the National Council for Air and Stream Improvement in 1969. The data used here are from 25 mills. These mills listed production capacities totalling 20,181 tons of pulp/day and reported use of bark and wood for fuel in the amount of 8,591 tons/day. Of the 8,591 tons used per day, 6,023 tons were burned in boilers utilizing fly-ash reinjection.

An estimate of the amount of bark used in the total industry is obtained by multiplying the amount of bark used in the 25 mills by the ratio of the total capacity of the industry, 109,908 tons/day,[4] to the capacity of the 25 mills. For boilers utilizing fly-ash reinjection, the amount of particulate discharged to the atmosphere is calculated as follows.

Assume 50% moisture content in the bark[10]
Assume 12% of dry bark discharged as particulate matter from the boiler when fly-ash is reinjected[10]

$$6{,}023 \times \frac{109{,}908}{20{,}181} \times (1-0.50) \times 0.12 = 1{,}960 \text{ tons/day discharged}$$

from the source
Assume a 95% operating efficiency of the cyclone collectors on the reinjection system
Assume 300 operating days/year
$1{,}960 \times 300 \times (1-0.95) = 29{,}500$ tons/year discharged to the atmosphere from bark boilers with fly-ash reinjection.

For boilers without fly-ash reinjection, the calculation is as follows. The amount of bark burned in these boilers is 2,568 tons/day. Of the 2,568 tons/day, 860, approximately one-third, were burned in boilers for which no fly-ash collectors were listed.

Assume 7% of dry bark discharged as particulate matter from the boiler[11]
Assume 50% moisture content in the bark

$$2{,}568 \times \frac{109{,}908}{20{,}181} \times (1-0.50) \times 0.07 = 488 \text{ tons/day}$$

discharged from the source
Assume two-thirds $(1-860 \div 2{,}568)$ of these boilers have dust collectors of 95% operating efficiency
$488 \times 300 \times (1-0.67 \times 0.95) = 52{,}800$ tons/year discharged to the atmosphere from bark boilers without fly-ash reinjection

The total amount of particulate emissions discharged to the atmosphere from bark boilers is thus estimated at 82,000 tons/year. This estimate does not include particulate matter from the combustion of coal and fuel oil in the bark boilers.

If the assumption be made that the 25 mills were operating at capacity, an emission factor for bark boilers can be calculated from the above data as follows:

$$8{,}591\ \frac{\text{tons}}{\text{day}}\ \text{wood} \times 2{,}000\ \frac{\text{lb.}}{\text{ton}} \times \frac{1\ \text{day}}{20{,}181\ \text{tons pulp}}$$

= 850 lb. wet bark burned/ton of pulp
Assume 50% moisture content
Assume 10% of bone dry bark going up stack
850 x 0.50 x 0.10 = 42.5 lb. particulate/ton of pulp produced.

Therefore, 42.5 lb/ton is the emission factor for the source and approximates the 35 lb/ton listed in Table 4.7-2.

4.7.4 Plywood, Particleboard, and Hardboard

The emissions from the manufacture of plywood, particleboard, and hardboard are estimated from data presented in a report on this part of the Forest Products Industry by the Mid-Willamette Valley Air Pollution Authority in Salem, Oregon.[12] The report lists emission factors for various operations in the manufacture of these products; these and the accompanying data in the report have been applied to the production nationwide. Particulate pollutants arise from drying and sanding of the finished products and from burning the bark, trim, sawdust, and sanderdust not sold or recycled. Burning is done either in wigwam burners or in boilers. The emissions from wigwam burners are considered to be included in the estimate for the total industry. The emissions from boilers are calculated as follows. Approximately 30% of the waste is burned in boilers; the emission factor for this combustion is 2.6 lb. particulate/ton of wood waste burned. The total amount of waste in plywood and by-product manufacturing averages approximately 475 dry tons/million sq. ft. (3/8 in. basis) of plywood. The estimated production of plywood in the United States in 1968 was 15,000,000,000 sq. ft. on a 3/8 in. basis.

$$15{,}000{,}000{,}000 \times \frac{475}{1{,}000{,}000} \times 0.30 \times \frac{2.6}{2{,}000} = 2{,}780\ \text{tons/year,}$$

particulate emissions from boilers

The dust from sanding machines is collected by cyclones; the average emission to the atmosphere is approximately 10% of the sanderdust produced. Sanderdust from the manufacture of plywood, particleboard, and hardboard comprises approximately 10% of the total waste from these plants, or 45 dry tons/million sq. ft. of plywood manufactured.

$$15{,}000{,}000{,}000 \times \frac{45}{1{,}000{,}000} \times 0.10 = 67{,}000\ \text{tons/year, particulate}$$

discharged from cyclones

The waste from veneer dryers averages approximately 250 lb. particulate/million sq. ft. of plywood.

$$15{,}000{,}000{,}000 \times \frac{250}{1{,}000{,}000} \times \frac{1}{2{,}000} = 3{,}750 \text{ tons/year, particulate}$$

from veneer dryers

The estimate for particulate emissions from plywood and by-products manufacture is tabulated as follows. Calculated emissions are rounded to the nearest thousand. Excluded are emissions from wigwam burners operated at plywood and by-product plants.

Boilers		3,000	tons particulate/year
Cyclones		67,000	
Veneer Dryers		4,000	
	Total	74,000	

The total amount of particulate pollutants from the Forest Products Industry is estimated at 6-3/4 million tons per year. Six million tons of this is from slash burning in the forests.

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4.8 Lime

Dust from the manufacture of lime comes mainly from kilns. Other sources are crushers and pulverizers, screens, hydrators, and bagging and bulk loading of product.

Emission factors and emissions calculated are shown in Table 4.8-1. Emission factors were obtained for films and rock crushers. No information was found on emissions for pulverizers, mills and hydrators. An emission factor for materials handling plus the other sources for which no information was found was assumed. Values of C_c and C_t used in the calculations are discussed in Chapter 5, p. 224.

Dust from rotary kilns is estimated at 5 to 15% of product,[1] which is a range of 100 to 300 lb. of dust discharged from the kiln per ton of product. A second source estimates dust loss at 5% of limestone charged, or 9% of lime produced,[2] which is 180 lb/ton. Two stack sampling results[3] list emission rates of 99 and 54 lb/ton of product for rotary kilns. Reference 4 lists a factor of 430 lb/ton processed; this would be approximately 215 lb/ton of product. Reference 2 lists an emission factor of 7.7 lb. of dust/hour from a vertical kiln producing 25 tons/day. On a process-weight basis, this rate is 7.4 lb. dust/ton of product. From conversation with personnel in the industry, production of lime from vertical kilns is estimated at 10% of the total. Based on these limited data an emission factor of 180 lb/ton was chosen for dust discharged from rotary kilns and coolers; a factor of 7 lb/ton is used for vertical kilns. Emission factors for kilns are considered to include emissions from coolers. Where coolers are utilized, the customary arrangement is to provide one system to collect dust from both kiln and cooler.

Calculation of particulate emissions from rotary kilns is as follows. (Calcining of lime in the pulp and paper industry is not included.)

P = 19,000,000 x 0.90 tons of lime produced per year (1968) in rotary kilns

e_f = 180 lb. of dust discharged from kilns per ton of lime produced

C_c = 93%, average operating efficiency of dust collectors installed on rotary kilns

C_t = 87%, percent of production capacity of rotary kilns on which dust collectors are installed

$$E = \frac{(19{,}000{,}000 \times 0.90)(180)(1-0.93 \times 0.87)}{2{,}000} = 294{,}000 \text{ tons}$$

dust discharged to the atmosphere from rotary kilns in 1968

TABLE 4.8-1

PARTICULATE EMISSIONS
LIME MANUFACTURE

Source	Quantity of Material	Emission Factor	Efficiency of Control (C_c)	Application of Control (C_t)	Net Control ($C_c \cdot C_t$)	Emissions ton/yr
I. Kilns and Coolers	18,000,000 tons lime (excl. pulp & paper)					
A. Rotary Kilns and Coolers	16,200,000 tons	180 lb/ton lime	0.93	0.87	0.81	294,000
B. Vertical Kilns	1,800,000 tons	7 lb/ton lime	0.97	0.40	0.39	4,000
C. Fluid-Bed Kilns	---					--
II. Minor Sources						
A. Stone Crushing and Screening						
1. Primary Crusher	28,000,000 tons of rock crushed for lime	22 lb/ton of rock crushed				
2. Secondary Crusher		2.0 lb/ton of rock crushed				
		24 lb/ton of rock crushed	0.80	0.25	0.20	264,000
3. Pulverizing, Quicklime			0.95	0.80	0.76	--
4. Milling, Hydrated Lime			0.95	0.80	0.76	--
B. Hydrator		--				
C. Materials Handling		--				
1. Conveyors						
a. Transfer Points						
b. Discharge to Bins, Stockpiles						
2. Elevators						
a. Boots		--				
b. Heads						
3. Shipment of Product						
a. Bagging Machines		--				
b. Bulk Loading		--				
(1) trucks						
(2) freight cars						
Assumed for hydrator plus materials handling		5 lb/ton of lime produced	0.95	0.80	0.76	11,000
				Total for Lime Manufacture		573,000

Calculation of particulate emissions from vertical kilns is as follows.

P = 19,000,000 x 0.10, tons of lime produced per year in vertical kilns (1968)
e_f = 7 lb/ton
C_c = 97%, average operating efficiency of dust collectors installed on vertical kilns
C_t = 40%, percent of production capacity of vertical kilns on which dust collectors are installed

$$E = \frac{(19{,}000{,}000 \times 0.10)(7)(1-0.97 \times 0.40)}{2{,}000} = 4{,}000 \text{ tons dust/year}$$

For crushing of the limestone, the emission factor is taken from Reference 4. For primary crushing, an emission factor of 22 lb. of dust per ton of rock crushed is taken as the average of data listed. To this factor is added the factor of 2 lb/ton for secondary crushing. The total factor for rock crushing is thus 24 lb. dust per ton of rock crushed. Dust from rock crushing is calculated as follows

P = 28,000,000 tons of rock crushed for manufacture of lime
e_f = 24 lb. dust per ton of rock crushed
C_c and C_t = same as for the crushed stone industry

$$E = \frac{(28{,}000{,}000)(24)(1-0.80 \times 0.25)}{2{,}000} = 264{,}000 \text{ tons of dust from rock crushed for lime}$$

No data were found for the amount of quicklime which is pulverized or the amount of hydrated lime which is milled. However, the total dust from these sources is considered insignificant.

Three stack samples from state air pollution control agencies give controlled emission factors of 3.7, 1.6, and 3.3 lb. particulate per ton of product for kilns. This rate is approximately 0.15% of the end product. If the entire industry operated at this dust-collection efficiency, the dust discharged to the atmosphere from kilns would be:

$$E = 19{,}000{,}000 \frac{\text{tons lime}}{\text{year}} \times 3 \frac{\text{lb. dust}}{\text{ton lime}} \times \frac{1}{2{,}000} \times \frac{\text{lb.}}{\text{ton}}$$

= 28,500 tons/year, a factor of 10 lower than calculated previously

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4.9 Clay Products

The clay products industries have as their finished materials a variety of articles that are essentially silicates. These products may be classified as: (1) whiteware; (2) heavy clay products; (3) refractories; and (4) enamels and enameled metal. The three main raw materials used in making common ceramic products are: (1) clay; (2) feldspar; and (3) sand. In addition to these three principal raw materials, there is a wide variety of other minerals, salts, and oxides that are used as fluxing agents and special refractory ingredients. Included are: Borax, soda ash, cryolite, alumina, chromite, and magnesite.1/

Clay or ceramic products are manufactured by a series of processes involving grinding, screening, calcining, blending of the raw materials, forming, drying or curing, firing and final cutting or shaping. Particulate emissions occur during handling of raw materials, grinding, calcining, screening and blending, and during cutting and shaping operations.

To facilitate emission calculations, the clay products industry will be grouped into three main categories:

1. Ceramic Clay
    a. Pottery and Stoneware
    b. Floor and Wall Tile
    c. Filter Activated Clays, Chemical, etc.
    d. Fillers
    e. Miscellaneous
2. Refractories
3. Heavy Clay Products

Emission factors and estimated emissions are summarized in Table 4.9-1. Information was obtained on emission factors for all the listed sources; however, very little information was obtained on dust-collection practices. A short discussion of dust collection in the industry is given in Chapter 5, p. 230.

The raw materials for all products in these categories undergo grinding and/or drying to some extent. The emission factors for these operations were taken from Reference 1. In Reference 1, the results of nine tests of controlled dryer exhaust gases were used to calculate emission factors. The uncontrolled emission factors, calculated using stack test data and assumed collector efficiencies, ranged from 14-110 lb/ton. An average of 70 lb/ton was chosen for dryers.

The emission factor for clay grinding was determined from test data on one clay grinding mill. Uncontrolled emissions from this mill,

TABLE 4.9-1

PARTICULATE EMISSIONS
CLAY PRODUCTS

Source	Quantity	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions tons/yr
I. Ceramic Clay	7,870,000 tons					
A. Grinding	60% of ceramics	76 lb/ton prod.	--	--	0.60	72,000
B. Drying	100% of ceramics	70 lb/ton prod.	--	--	0.60	110,000
II. Refractories	3,440,000 tons					
A. Kiln-Fired						
1. Calcining	20% of kiln-fired	200 lb/ton prod.	--	--	0.64	25,000
2. Drying	30% of kiln-fired	70 lb/ton prod.	--	--	0.64	13,000
3. Grinding	100% of kiln-fired	76 lb/ton prod.	--	--	0.64	47,000
B. Castable Refracts.	550,000 tons	225 lb/ton prod.	--	--	0.77	14,000
C. Dead-Burned Magnesite	125,000 tons	250 lb/ton prod.	--	--	0.56	7,000
D. Mortars	120,000 tons					
1. Grinding		76 lb/ton prod.	--	--	0.60	2,000
2. Drying		70 lb/ton prod.	--	--	0.60	2,000
E. Gunning Mixes	250,000 tons	76 lb/ton prod.	--	--	0.60	4,000
III. Heavy Clay Products	23,700,000 tons					
A. Grinding	20% of heavy clay	76 lb/ton prod.	--	--	0.60	72,000
B. Drying	30% of heavy clay	70 lb/ton prod.	--	--	0.60	99,000
	Total for Clay Products					467,000

Note: Values reported for net control are assumed numbers.

calculated from the test data and assumed collector efficiency, ranged from 64-88 lb/ton. An average value of 76 lb/ton was chosen for clay grinders.[1] The collector was a cyclone; the assumed efficiency was 75%.

The above emission factors for drying and grinding of clay are assumed to be applicable for these processes in all phases of the clay products industry. Emissions from each major category of clay products are discussed in the following sections.

4.9.1 Ceramic Clay

The manufacture of the clay products grouped in this category involve conditioning of the basic ores by several methods. These include the separation and concentration of the minerals by screening, floating, wet and dry grinding, and blending of the desired ore varieties. The basic raw materials in ceramic clay manufacture are kaolinite and montmorillonite clays. These clays are refined by separation and bleaching, blended, and after kiln drying are formed into whiteware, stoneware, and other products such as diatomaceous earth used as a filter aid.

The manufacture of filter and activated clays includes grinding and wet or acid treating followed by drying and regrinding.

Particulate emissions occur from the drying and grinding steps. The emission factors for these operations are 70 and 76 lb/ton, respectively.

Production figures for this category in 1968 were:

1. Pottery and Stoneware - 514,000 tons
2. Floor and Wall Tile - 577,000 tons
3. Filters, Catalyst, Chemicals, etc. - 3,781,000 tons
4. Fillers - 3,001,000 tons

Data were not found on the quantity of material subjected to dry grinding or drying. However, from the process descriptions it would appear that all the raw material is dried and that 60% is probably ground by dry methods.

The degree of application of control is assumed to be 75%, and the average efficiency of control equipment is assumed to be 80%.

Emissions were calculated as follows.

Grinding

$$E = \frac{(7.87 \times 10^6 \text{ tons/yr})(0.60)(76 \text{ lb/ton})(1-0.75 \times 0.80)}{2 \times 10^3 \text{ lb/ton}} =$$

71,800 tons/yr

Drying

$$E = \frac{(7.87 \times 10^6 \text{ tons/yr})(70 \text{ lb/ton})(1-0.75 \times 0.80)}{2 \times 10^3 \text{ lb/ton}} =$$

110,180 tons/yr

Losses from stockpiles were not estimated. Total estimated particulate emissions from this category are, therefore, 182,000 tons/year.

4.9.2 Refractories

Refractories are produced by kiln-fired and castable techniques. Emissions for each process are outlined in the following paragraphs.

4.9.2.1 Kiln-Fired: The multiplicity of refractory products results in a highly variable process flowsheet. Depending upon the desired product, raw materials may be calcined or dried prior to mixing and blending.

The decision to calcine or dry the raw material depends upon its end use. The type of clay, refractory brick, and ultimate density are among the factors that influence the decision.[2,3] Discussions with contacts in the refractories industry indicate that approximately 20% of the raw material is calcined, and 30% of the total clay and calcine goes through a dryer.[2,3]

Emission factors for rotary kilns were obtained from industry and literature sources. Reference 2 provided factors of 65, 100, and 135 lb/ton for three plants. Reference 3 indicated that emissions varied from 200-400 lb/ton. The value of 400 lb/ton was for a plant operating over capacity. European data for rotary kilns indicate emission factors ranging from 10-15% of kiln input.[4] The range of emission factors from these sources is 65-400 lb/ton. An average value of 200 lb/ton was selected.

Dryer emission factors reported in European data ranged from 0.5-8% of dryer input, with the average value being approximately 4%.[5] This corresponds to 80 lb/ton and agrees closely with the value of 70 lb/ton reported in Reference 1. The value of 70 lb/ton was selected.

The degree of application of control devices and their average efficiency was estimated from discussions with industry representatives. Plants constructed in the last 5-10 years generally have settling chambers and cyclones on kilns and dryers.[2] Reference 3 indicated that in that company all kilns and dryers were equipped with some type of control device. The estimated overall efficiency of the equipment was 80% on a mass basis. On an industry wide basis, it was assumed that the degree of application of control was 80%, and the overall average efficiency of control equipment was 80%.

Production of kiln-fired clay refractories totaled 3.44 million tons in 1969.[6]

Emissions from kiln-fired refractories plants were calculated as follows.

Calcining (20% of raw material is calcined)

$$E = \frac{(3.44 \times 10^6 \text{ tons/yr})(0.2)(200 \text{ lb/ton})(1-0.80 \times 0.80)}{2 \times 10^3} =$$

24,800 tons/yr

Drying (30% of raw material is dried)

$$E = \frac{(3.44 \times 10^6 \text{ tons/yr})(0.3)(70 \text{ lb/ton})(1-0.80 \times 0.80)}{2 \times 10^3} =$$

13,000 tons/yr

Grinding (all raw material ground)

$$E = \frac{(3.44 \times 10^6 \text{ tons/yr})(76 \text{ lb/ton})(1-0.80 \times 0.80)}{2 \times 10^3} =$$

47,120 tons/yr

Emissions from storage bins and stockpiles were not estimated because of lack of data regarding quantities stored and emission rates. Total particulate emission from refractory clay manufacture is, therefore, estimated to be 84,920 tons/year.

4.9.2.2 Castable: Castable or fused-cast refractories are manufactured by carefully blending such components as alumina, zirconia, silica, chrome, and magnesia, melting the mixture in an electric arc furnace at temperatures of 3200-4500°F, pouring into molds, and slowly cooling to the solid state.

Particulate emissions occur from the drying, crushing, handling and blending phases of this process, the actual melting process, and in the molding phase. Emission factors for cast refractories were taken from Reference 1, and are summarized in Table 4.9-2. The emission factors in Table 4.9-2 are based on limited data and cover a wide range.

TABLE 4.9-2

PARTICULATE EMISSIONS FROM CASTABLE REFRACTORIES MANUFACTURING

	Emissions, Lb/Ton of Feed Material		
Process	Uncontrolled	Controlled	Type of Control
Raw Material Dryer	30	0.3	Baghouse
Raw Material Crushing and Processing	120 (100-190)	7 45	Scrubber Cyclone
Electric Arc Melting	50 (10-88)	0.8 10	Baghouse Scrubber
Curing Oven	Neg.		
Molding and Shakeout	25	0.3	Baghouse

It is assumed that all raw materials go through drying and crushing, prior to melting. An overall emission factor of 225 lb/ton will, therefore, be used for calculating emissions. It is also assumed that the degree of application of control is 85% and that the average efficiency of control is 90%.

Production of castable refractories totaled 550,000 tons in 1969.[6]

Emissions from castable refractory manufacture were calculated as follows.

$$E = \frac{(5.5 \times 10^5 \text{ tons/yr})(225 \text{ lb/ton})(1-0.85 \times 0.90)}{2 \times 10^3} = 14{,}300 \text{ tons/yr}$$

4.9.2.3 Dead-Burned Magnesite: Calcined or "dead-burned" magnesite is obtained by firing naturally occurring magnesium carbonate to temperatures of 1540-2000°C. The calcining may be done in rotary or vertical kilns. Reference 5 lists an emission factor of 8-10% of the kiln input for vertical kilns, while Reference 4 indicated that emissions may be as high as 25% of the charge for rotary kilns. An emission factor of 250 lb/ton is assumed to represent an average for vertical and rotary kilns. The degree of application of control is assumed to be 70%, and the average efficiency of control equipment is assumed to be 80%. Production for the year 1969 was 119,831 tons.

Emissions were calculated as follows.

$$E = \frac{(1.2 \times 10^5 \text{ tons/yr})(250 \text{ lb/ton})(1-0.80 \times 0.70)}{2 \times 10^3} = 6,600 \text{ tons/yr}$$

4.9.2.4 Mortars, Plastic Refractories, Ramming Mixes, and Gunning Mixes: Mortars consist of finely ground refractory grains and plasticizers to lay up refractory brick. They may be manufactured wet (premixed) or dry, and are generally compounded in cylindrical paddle-type mixers. It is assumed that all these materials go through drying and fine grinding. The emission factor for drying is assumed to be 70 lb/ton, and that for grinding 76 lb/ton. The degree of application of control is assumed to be 75%, and the average efficiency of control equipment is assumed to be 80%. Production for the year 1969 was 120,326 tons/year.

Emissions were calculated as follows.

Grinding

$$E = \frac{(1.2 \times 10^5 \text{ tons/yr})(76 \text{ lb/ton})(1-0.80 \times 0.75)}{2 \times 10^3} = 1,824 \text{ tons/yr}$$

Drying

$$E = \frac{(1.2 \times 10^5 \text{ tons/yr})(70 \text{ lb/ton})(1-0.80 \times 0.75)}{2 \times 10^3} = 1,680 \text{ tons/yr}$$

Ramming mixes are mixtures of refractory grains and plastic clays from which a plastic mixture is formed by adding water. Coarse refractories are used, and it is assumed that fine grinding and drying do not occur. Therefore, particulate emissions are assumed negligible.

Gunning mixes are mixtures of refractory grains which are applied by a spray gun. Gunning mixes are generally finer grained than regular castables and plastics. It is assumed that these materials are all subjected to fine grinding, and that control practice corresponds to that assumed for mortar production. Production of mixes in 1969 was 249,385 tons/year.[6]

Emissions were calculated as follows.

$$E = \frac{(2.5 \times 10^5 \text{ tons/yr})(76 \text{ lb/ton})(1-0.80 \times 0.75)}{2 \times 10^3} = 3{,}800 \text{ tons/yr}$$

4.9.3 Heavy Clay Products

The manufacture of brick and related products such as clay pipe, common brick, drain tile, and kindred products involves grinding, screening, blending of the raw materials, forming, drying or curing, firing and final cutting or shaping.

Particulate emissions occur during handling of raw materials, grinding, screening, and blending, and during cutting and shaping operations.

Fine grinding (i.e., beyond secondary crushing) is not usually necessary for heavy clay products. When grinding is performed, wet grinding is generally preferred. No data are available regarding the quantity of material actually ground, or that ground by the dry method. It is assumed that 20% of the raw materials undergo dry grinding.

The extent of raw material drying is also not known, and it is assumed that 30% of the raw material is dried.

Emission factors are 70 lb/ton for dryers and 76 lb/ton for clay grinders.

The production of heavy clay products totaled 23.7 million tons in 1968.[8]

The degree of application of control is assumed to be 75%, and the average efficiency of control equipment is assumed to be 80%.

Emissions were calculated as follows.

Grinding

$$E = \frac{(23.7 \times 10^6 \text{ tons/yr})(0.2)(76 \text{ lb/ton})(1-0.80 \times 0.75)}{2 \times 10^3} =$$

72,000 tons/yr

Drying

$$E = \frac{(23.7 \times 10^6 \text{ tons/yr})(0.3)(70 \text{ lb/ton})(1-0.80 \times 0.75)}{2 \times 10^3} =$$

99,500 tons/yr

Losses from stockpiles were not estimated as no data were found on tannage stockpiled or storage procedures. Emissions from heavy clay products curing and firing are negligible unless coal is used to fire the kilns. Coal-fired kilns are not widely used and emissions from these units were not estimated.

Total particulate emissions from heavy clay manufacture are estimated to be 171,500 tons/year.

Estimated emissions from clay or ceramics products are summarized below.

I.	Ceramic Clay		182,000 tons/yr
II.	Refractories		
	a. Kiln-fired	- 84,920	
	b. Castable	- 14,300	
	c. Dead-Burned Magnesite	- 6,600	
	d. Mortars	- 3,500	
	e. Gunning Mixes	- 3,800	
		113,120	113,120 tons/yr
III.	Heavy Clay Products		171,500 tons/yr
	Total		466,620 tons/yr

Table 4.9-1 presents a detailed breakdown of the factors that lead to these numbers.

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CLAY PRODUCTS

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4.10 Primary Nonferrous Metals

The nonferrous metals produced in sufficient quantity to be of significance with regard to quantity of particulate air pollutants are aluminum, copper, lead, and zinc. The designation, "primary," indicates the extractive industries. The nature of the raw materials differentiates the primary industries from the secondary industries, for which the raw materials are scrap metal. Aluminum is obtained from its oxide; copper, lead, and zinc are obtained mostly from their sulfides. To process aluminum oxide (alumina), electrolytic refining is the most economical means. The processing of copper, lead and zinc utilizes roasting to remove sulfur and smelting to refine the metal. For high purity, electrolysis is also used as a final refining step for copper and zinc. Over 85% of primary copper production and approximately 40% of primary zinc is electrolytically refined.

A fume of submicron size is a characteristic of particulate pollutants from the primary nonferrous industries.

A summary of emission factors and estimated particulate emissions is shown in Table 4.10-1. Information and data on emission factors were obtained for most of the processing equipment in the industry. Emissions data was not found for fire refining and slag furnaces used in copper smelting or for drossing kettles, softening furnaces, de-silvering kettles, cupeling furnaces and refining kettles used in the lead industry. Value of C_c and C_t used in the calculations are discussed in Chapter 5, pp. 225-230.

The main source of data and information in tthis chapter is the report, "Systems Study for Control of Emissions, Primary Nonferrous Smelting Industry," prepared by the Arthur G. McKee Company for the Division of Process Control Engineering of NAPCA.

All production figures used in estimating quantities of emissions were obtained from the 1968 Minerals Yearbook.[9]

4.10.1 Aluminum

Particulate pollution from the production of aluminum comes from the following sources: (1) grinding and calcining in the preparation of alumina, (2) electrolytic cells, (3) ovens used to bake electrodes, (4) holding furnaces; and (5) handling of materials. Over 85% of the bauxite used in this country is imported; and most of it is ground and dried before shipment. Emissions from the beneficiation of bauxite are thus assumed to be insignificant. To produce alumina, bauxite is ground and reacted with chemicals to produce the hydroxide, $Al(OH)_3$, which is calcined to dehydrate the

TABLE 4.10-1

PARTICULATE EMISSIONS
PRIMARY NONFERROUS METALS INDUSTRIES

	Quantity of Material	Emission Factor	Efficiency of Control (C_c)	Application of Control (C_t)	Net Control ($C_c \cdot C_t$)	Emissions (tons/yr)
I. Aluminum						
A. Preparation of Alumina						
1. Grinding of Bauxite	13,000,000 tons of bauxite	6 lb/ton of bauxite	-	-	0.80	8,000
2. Calcining of Hydroxide	5,840,000 tons of alumina	200 lb/ton of alumina	-	-	0.90	58,000
B. Aluminum Mills						
1. Soderberg Cells						
a. Horizontal stud	800,000 tons of aluminum	144 lb/ton of aluminum	0.40	1.0	0.40	35,000
b. Vertical stud	700,000 tons of aluminum	84 lb/ton of aluminum	0.64	1.0	0.64	10,000
2. Pre-Bake Cells	1,755,000 tons of aluminum	63 lb/ton of aluminum	0.64	1.0	0.64	20,000
C. Materials Handling	3,300,000 tons of aluminum	10 lb/ton of aluminum	0.90	0.35	0.32	11,000
	Total from primary aluminum industry					142,000
II. Copper						
A. Ore Crushing	170,000,000 tons of ore	2 lb/ton of ore	0.0	0.0	0.0	170,000
B. Roasting	40% of 1,437,000 tons of copper	168 lb/ton copper	0.85	1.0	0.85	7,000
C. Reverberatory Furnace	1,437,000 tons of copper	206 lb/ton copper	0.95	0.85	0.81	28,000
D. Converter	1,437,000 tons of copper	235 lb/ton copper	0.95	0.85	0.81	33,000
E. Fire Refining						
F. Slag Furnaces						
G. Materials Handling: Ore, Limestone Slag, etc.	1,437,000 tons of copper	10 lb/ton copper	0.90	0.35	0.32	5,000
	Total from primary copper industry					243,000
III. Zinc						
A. Ore Crushing	18,000,000 tons of ore	2 lb/ton of ore	0.0	0.0	0.0	18,000
B. Roasting						
1. Fluidized-Bed, Suspension	75% of 1,020,000 tons of zinc	2,000 lb/ton zinc	0.98	1.0	0.98	15,000
2. Ropp, Multiple-Hearth	15% of 1,020,000 tons of zinc	333 lb/ton zinc	0.85	1.0	0.85	4,000
C. Sintering and Sinter Crushing	60% of 1,020,000 tons of zinc	180 lb/ton zinc	0.95	1.0	0.95	3,000
D. Distillation	60% of 1,020,000 tons of zinc		0.0	0.0	0.0	15,000
E. Materials Handling	1,020,000 tons of zinc	7 lb/ton zinc	0.90	0.35	0.32	2,000
	Total from primary zinc industry					57,000
IV. Lead						
A. Ore Crushing	4,500,000 tons of ore	2 lb/ton ore	0.0	0.0	0.0	4,000
B. Sintering	467,000 tons of lead	520 lb/ton lead	0.95	0.90	0.86	17,000
C. Blast Furnace	467,000 tons of lead	250 lb/ton lead	0.85	0.98	0.83	10,000
D. Drossing Kettle		-				
E. Softening Furnace		-				
F. De-Silvering Kettles		-				
G. Cupeling Furnaces		-				
H. Refining Kettles		-				
I. Dross Reverberatory Furnace	467,000 tons of lead	20 lb/ton lead	-	-	0.50	2,000
J. Materials Handling	467,000 tons of lead	5 lb/ton lead	0.90	0.35	0.32	1,000
	Total from primary lead industry					34,000
	Total from nonferrous metals industries					476,000

hydroxide and form alumina. Data from industrial sources[1] indicate that the emission rate from the calcining of the hydroxide is approximately 200 lb/ton of alumina produced. For an emission factor for the grinding of bauxite, the process is assumed to be the equivalent of the pulverizing of phosphate rock for the manufacture of wet-process phosphoric acid, and the emission factor for this process, 6 lb/ton of rock ground, is assumed applicable to the grinding of bauxite. The efficiency of dust collection in the grinding of bauxite is assumed to be 80%.

The amount of particulate pollution from the preparation of alumina is estimated as follows:

1. Grinding of bauxite

$$E = 13{,}000{,}000 \text{ tons bauxite} \times \frac{6 \text{ tons part. generated}}{2{,}000 \text{ tons of bauxite}}$$

$$\times \frac{(1-0.8) \text{ tons part. to atm.}}{\text{tons generated}} = 7{,}800 \text{ tons}$$

2. Calcining of alumina

$$E = 5{,}840{,}000 \text{ tons of alumina} \times \frac{200 \text{ tons part. generated}}{2{,}000 \text{ tons alumina}}$$

$$\times \frac{(1-0.9) \text{ tons part. to atm.}}{\text{tons generated}} = 58{,}400 \text{ tons}$$

Emissions from electrolytic cells vary with the type of cell. The Soderberg cells, horizontal stud and vertical stud, have higher emission rates than pre-bake cells. In Soderberg cells, the anodes are baked in the cell from a paste which flows continuously to the cell. The baking of the paste produces a hydrocarbon mist which is added to the particulate effluent from the materials in the bath. While the pre-bake cell has a lower emission rate than the Soderberg cells, mills using pre-bake cells discharge particulate pollutants from the ovens in which these anodes are baked.

The furnaces used for holding the molten metal after it is tapped from the electrolytic cells are also a source in all aluminum mills. Emissions from this source include compounds of chlorine, which is used as a purifying reagent. Table 4.10-2 lists the various emission factors used to calculate emissions from aluminum mills.[2]

TABLE 4.10-2

EMISSION FACTORS FOR VARIOUS SOURCES IN ALUMINUM MILLS

Source	Emission Factor (lb. particulate per ton of Al)
1. Electrolytic Cells	
A. Soderberg	
1. Horizontal stud	140
2. Vertical stud	80
B. Pre-bake	55
2. Anode Ovens	4
3. Holding Furnace	4

To be noted in the calculations is the value of 1.00 representing extent of pollution control in the industry. This extent of control is due to the fact that all "pot lines," i.e., rows of electrolytic cells in the mills, have wet scrubbers primarily for control of gaseous fluoride emissions. The relatively low values for the efficiencies of collection of particulate emissions, 0.40 and 0.64, result from the design of the scrubbers for collection of gaseous emissions. The quantity of emissions from aluminum mills is estimated as follows:

1. Soderberg, horizontal stud
   Emission factor: (140 + 4) lb/ton of aluminum produced
   Production: 800,000 tons of Al

$$E = \frac{(800{,}000)(144)(1-0.40 \times 1.00)}{2{,}000} = 34{,}600 \text{ tons}$$

2. Soderberg, vertical stud
   Emission factor: (80 + 4) lb/ton of aluminum produced
   Production: 700,000 tons of Al

$$E = \frac{(700{,}000)(84)(1-0.64 \times 1.0)}{2{,}000} = 10{,}600 \text{ tons}$$

3. Pre-Bake
   Emission factor: (55 + 4 + 4) lb/ton of aluminum produced
   Production: 1,755,000 tons of Al

$$E = \frac{(1{,}755{,}000)(63)(1-0.64 \times 1.0)}{2{,}000} = 20{,}000 \text{ tons}$$

To calculate a quantity for dust from materials handling, the same factor as that for this source in the copper industry is used, i.e., 10 lb/ton of aluminum produced. The quantity is calculated as follows:

$$E = 3{,}300{,}000 \text{ tons Al} \times \frac{10 \text{ lb.}}{\text{ton of Al}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} \times (1-0.90 \times 0.35) = 11{,}000 \text{ tons}$$

Table 4.10-1 shows that the emissions from electrolytic cells are 65,000 tons/year for a production of 3,300,000 tons of aluminum. The emission rate is approximately 40 lb/ton of aluminum produced. The state of Washington, in which approximately 30% of aluminum is produced, reports 12,500 tons of particulate emissions for a production of 1,000,000 tons of aluminum. This leads to an emission rate of 25 lb/ton.6/ Two plants using pre-bake cells are reported to have reduced their emission rates to "close to 15 lb/ton," which is the Washington standard for aluminum mills.

4.10.2 Copper

Particulate pollution from the smelting of copper comes from the following sources: (1) crushing of ore, (2) roasters, (3) smelting furnaces, (4) converters; and (5) handling of materials. Slag furnaces and furnaces for fire refining are of less significance.

4.10.2.1 Crushing of Ore: Estimate of particulate emissions from crushing of ore are based on the emission factors for these operations in the crushed stone industry.3/ The factor used here is the sum of the factors for primary and secondary crushing--2 lb/ton of rock through the primary crusher. Copper ore is crushed first in gyratory crushers and then in cone crushers; water is then added to form a slurry which is ground to the size required for making concentrates. Dust is thus produced only in the crushers. The amount of dust from crushing is estimated as follows:

$$E = 170{,}000{,}000 \frac{\text{tons ore}}{\text{year}} \times \frac{2 \text{ lb. dust}}{\text{ton ore}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 170{,}000 \text{ tons}$$

4.10.2.2 Roasting: Roasting is done in copper smelting only on ores in which the sulfur content is relatively high. Of 16 copper smelters in the United States, seven roast their concentrates. The others charge their concentrates directly to the reverberatory furnaces. It is assumed that the seven plants which roast concentrates account for 40% (7/16) of the production of refined copper.

The emission factor is obtained from data on a flow diagram of a hypothetical model of a copper smelter utilizing a roaster.[4]

dust collected from roaster	18.5 tons
dust to atmosphere	0.9
dust from roaster	19.4
tons copper produced	230

$$e_f = \frac{19.4 \text{ tons dust}}{230 \text{ tons Cu}} \times 2{,}000 \text{ lb.} = \frac{168 \text{ lb. dust}}{\text{ton Cu}}$$

These data are for a fluid-bed roaster. Not all roasters in use are fluid-bed roasters; however, these roasters have been in use in the industry for over 10 years, and recent installations have been of the fluid-bed type. It is assumed that the emission factor calculated here is applicable to the industry. Estimate of the dust from roasters is as follows:

$$E = (1{,}437{,}000 \times 0.40) \text{ tons Cu from roasted concs.} \times \frac{168 \text{ lb. dust}}{\text{ton Cu}}$$

$$\times (1 - 0.85 \times 1.0) \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 7{,}250 \text{ tons}$$

4.10.2.3 Reverberatory Furnace: Data to calculate the emission factor for furnaces were obtained from the same source as the data used to calculate the emission factor for roasters. Data were obtained from two flow diagrams, one is a model for a plant without roasters.[4,5] The emission factors are 201 lb. particulate per ton of copper produced for the plant with no roasting and 212 lb/ton for the plant utilizing roasting. The average of the two factors, 206 lb/ton, is used. Estimate of the emissions from reverberatory furnaces is as follows:

$$E = 1{,}437{,}000 \text{ tons Cu} \times \frac{206 \text{ lb. particulate}}{\text{ton Cu}} \times (1 - 0.95 \times 0.85)$$

$$\times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 28{,}100 \text{ tons}$$

4.10.2.4 Converters: Data to calculate the particulate emissions from converters are obtained from the same source as the data used to calculate the emission factors for roasters and reverberatory furnaces. The average emission factor for converters obtained from data on the two flow diagrams is 245 lb. particulate per ton of copper produced. Estimate of the emissions from converters is as follows:

$$E = 1{,}437{,}000 \times \frac{245}{2{,}000} \times (1-0.95 \times 0.85) = 33{,}300 \text{ tons}$$

4.10.2.5 Handling of Materials: The estimate of dust from the handling of materials is based on a factor of 1.7 lb/ton reported for the crushed stone industry. Included in the operations of materials handling are "general screening, conveying and handling."[7] This factor is increased to 10 lb. dust/ton of copper produced as the emission rate for handling solid materials consumed in and produced by the smelting of copper. (See discussion of emission factor for materials handling in Section 4.5.8.) Estimate of the amount of dust from materials handling is as follows:

$$E = 1{,}437{,}000 \text{ tons Cu} \times \frac{10 \text{ lb. dust}}{\text{ton Cu}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} \times (1-0.90 \times 0.35) = 4{,}900 \text{ tons/yr}$$

Table 4.10-1 shows that the emissions from the process equipment (roasters, furnaces, converters) total 67,000 tons for a production of 1,437,000 tons of copper. The rate of emissions is approximately 90 lb/ton of copper produced. Data from the state of Arizona[8] for smelters which account for over 50% of copper production show an emission rate of 19 lb/ton of concentrate. If an average of 25% Cu is assumed for the concentrate, the emission rate for the Arizona data is 75 lb/ton of copper produced.

4.10.3 Zinc

Particulate emissions from primary zinc smelting come from (1) crushing of ore, (2) roasting of concentrates, (3) sintering, (4) distillation; and (5) materials handling. Slag-fuming furnaces, which distill zinc from the slags from lead furnaces, are a less significant source.

4.10.3.1 Crushing of Ore: The emission factor for dust from crushing of ore is the same as that used for copper ore--2 lb/ton of ore crushed. Data on quantities of ore mined and the assay of zinc in them are not readily available. Reference 11 reports the recoverable zinc content of domestic ores mined in 1968 as 529,446 tons. Reference 12, published in 1947, states that the "average zinc content of ores mined in this country is about 3%." From these data, the quantity of ore mined is calculated as 17,600,000 tons. The quantity of dust from crushing this amount of ore is estimated as follows:

$$E = 17{,}600{,}000 \text{ tons ore} \times \frac{2 \text{ lb. dust}}{\text{ton ore}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 17{,}600 \text{ tons/yr}$$

4.10.3.2 Roasting: Roasting of zinc concentrates is done in a variety of roasters. The oldest type utilizes a raking action to move the concentrate through the roaster. The newer types utilize a pneumatic-suspension principle in which hot air is blown through the concentrate and which requires a finely ground concentrate. Most prominent among the latter type has been the fluid-bed roaster; however, in the zinc industry a "fluid-column" roaster has been developed, in which the feed is in the form of pellets and the discharge does not require sintering. Fluid-bed roasters have high rates of dust emissions; 70-85% of the concentrate charged is carried out of the roaster in the effluent gas stream. The fluid-column roaster is reported to generate dust in the amount of only 17-18% of the feed.

Approximately 75% of zinc production comes from plants which use either fluid-bed or suspension roasters. The suspension roaster utilizes mechanical rakes, but the emission rate is similar to the rate for fluid-bed roasters. The following data on the amount of dust generated are obtained from the literature.

Fluid-bed roasters
  20-77% of feed[9]
  70-85%[4]
Suspension (flash) roasters
  60% of feed[9]
  50%

From these data a value of 60% is taken as a representative emission rate for the 75% of the industry that utilizes fluid-bed and suspension roasting. Concentrates fed to roasters are assumed to average 60% Zn. The emission factor for fluid-bed and suspension roasters is thus:

$$e_f = \frac{0.6 \text{ ton dust}}{\text{ton feed}} \times \frac{2{,}000 \text{ lb.}}{\text{ton}} \times \frac{100 \text{ tons feed}}{60 \text{ tons Zn}} = \frac{2{,}000 \text{ lb. dust}}{\text{ton Zn produced}}$$

The dust emissions from this segment of the industry are estimated as follows:

$$E = (1{,}020{,}000 \times 0.75)(2{,}000)\left(\frac{1}{2{,}000}\right)(1-1.0 \times 0.98) = 15{,}300 \text{ tons}$$

Of the other 25% of production, approximately 10% is from oxide ores which are not roasted. The remaining 15% is roasted in Ropp or multiple-hearth roasters. The emission rates for these roasters range from 5-15% of the feed; 10% is taken as an average. The emission factor for a concentrate of 60% Zn is 333 lb. dust per ton of zinc produced. The quantity of dust emissions from roasting for this segment of the industry is estimated as follows:

$$E = (1{,}020{,}000 \times 0.15)\left(\frac{333}{2{,}000}\right)(1\text{-}1.0 \times 0.85) = 3{,}830 \text{ tons/yr}$$

4.10.3.3 Sintering: Dust comes from sintering machines and crushing of the sinter. Five to ten percent of feed to the sinter machines, which averages 65% Zn, is carried out in the effluent gas stream. An emission factor is calculated as approximately 250 lb. dust per ton of zinc produced. Information from an industrial source gives an emission rate of approximately 0.04 ton of dust per ton of sinter produced. At an assay of 65% Zn, the emission factor on a basis of ton of zinc produced would be 125 lb/ton. The average of these factors, 180 lb/ton, is used to estimate the quantity of emissions. In making this estimate, account must be taken of the zinc produced electrolytically since the roasted concentrate used for electrolytic production is not sintered. Approximately 40% of zinc production is by electrolysis.[9]

$$E = \frac{(1{,}020{,}000 \times 0.60)(180)(1\text{-}1.0 \times 0.95)}{2{,}000} = 2{,}750 \text{ tons of dust from sintering machines}$$

4.10.3.4 Distillation: Because zinc vapor burns readily in air, a minute quantity of vapor is allowed to escape from condensers in order to prevent the entrance of air. Information from an industrial source[10] indicates that the emission rate is 12 lb. of particulate (zinc oxide) per ton of zinc produced. An emission rate of 0.5% per ton of zinc in the ore is published in the literature.[13] The quantity of particulate emissions from distillation is estimated as follows:

$$E = (1{,}020{,}000 \times 0.60)\left(\frac{12}{2{,}000}\right) = 3{,}680 \text{ tons}$$

Also a source of pollution in the distillation process is broken retorts, the loss from which may exceed the loss from venting condensers. This loss is reported as 1.8% of zinc in the ore and is computed as the difference between accountable disposition of zinc in the smelting process and the amount of zinc which entered the process.[13] Since recovery of zinc in the ore exceeds 90%, the emission factor based on ton of zinc produced would be approximately the same as the factor based on ton of zinc in the ore. The quantity of particulate emissions from broken retorts is estimated as follows:

$$(1{,}020{,}000 \times 0.60)(0.018) = 11{,}016 \text{ tons}$$

The total particulate emissions from distillation are thus estimated at 15,000 tons.

4.10.3.5 Materials Handling: The emission factor for materials handling in zinc smelting is set in relation to the factor set for this source in the copper industry. Since the ratio of ore consumed to metal obtained is lower for zinc than for copper, the emission factor is lowered. A factor of 7 lb. dust per ton of zinc produced is assumed. The amount of dust from materials handling is estimated as follows:

$$E = (1{,}020{,}000)\left(\frac{7}{2{,}000}\right)(1-0.90 \times 0.35) = 2{,}430 \text{ tons}$$

4.10.4 Lead

The main sources of particulate emissions in lead smelting are: (1) ore crushing; (2) sintering; (3) blast furnaces; (4) dross reverberatory furnaces; and (5) materials handling.

4.10.4.1 Crushing of ore: The emission factor for dust from crushing of lead ore is the same as that used for the crushing of zinc and copper ores--2 lb. dust per ton of ore crushed. The quantity of ores crushed is an estimated quantity. The recoverable lead content of ores mined in 1968 was 359,000 tons;[11] the assay of lead ore was 6 to 10% Pb.[14] With the assumption that the average Pb assay is 8%, the quantity of ore mined is calculated as 4,500,000 tons. The quantity of dust from crushing this amount of ore is estimated as follows:

$$E = 4{,}500{,}000 \text{ tons ore} \times \frac{2 \text{ lb. dust}}{\text{ton ore}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 4{,}500 \text{ tons}$$

4.10.4.2 Sintering: The dust and fume load is usually from 5 to 20% of the feed. Average assay of lead in the feed to sinter machines is 37% Pb. The range of emissions calculated from these data is as follows:

$$e_f = (0.05\text{-}0.20) \times \frac{2{,}000 \text{ lb. dust}}{\text{ton feed}} \times \frac{1 \text{ ton feed}}{0.37 \text{ ton Pb}}$$

$$= \frac{260\text{-}1{,}040 \text{ lb. dust}}{\text{ton Pb produced}}$$

Since the geometric mean has been found to approximate the median more closely than the arithmetic mean for wide ranges of emission factors, the geometric mean, 520 lb. dust per ton of lead produced, is used to estimate the dust emissions from sintering. Estimate of quantity of dust from sintering is as follows.

$$E = (467{,}000)\left(\frac{520}{2{,}000}\right)(1\text{-}0.95 \times 0.90) = 17{,}000 \text{ tons/yr}$$

4.10.4.3 Blast Furnaces: Information on particulate-emission rates for blast furnaces is limited to rates expressed on a time basis, tons of dust per 24-hr. period, in a flow diagram.[15/] Listed are 9.7 tons of dust from the blast furnace and 22.0 tons of dust from the sintering machines. An emission factor for blast furnaces is obtained as a ratio to the emission factor for sintering.

$$e_f = \frac{\text{9.7 tons dust from blast furnaces}}{\text{22.0 tons dust from sintering}} \times \frac{\text{520 lb. dust from sintering}}{\text{ton Pb produced}}$$

$$= \text{250 lb. dust from blast furnace per ton of lead produced}$$

The quantity of dust emissions from blast furnaces is estimated as follows:

$$E = (467{,}000)\left(\frac{250}{2{,}000}\right)(1\text{-}0.85 \times 0.98) = 9{,}900 \text{ tons}$$

4.10.4.4 Dross Reverberatory Furnaces: The dross in lead refining comes from the molten material tapped from the blast furnaces. The molten material is the blast-furnace bullion. The dross contains up to 50% lead[9/] as well as recoverable amounts of copper, and it is processed in a reverberatory furnace.

The emission factor for dross reverberatory furnaces is estimated from data in Reference 9. Dust from the reverberatory is approximately 80 lb/ton of the dross charged to it, and the dross charged is 10-30% of the blast-furnace bullion. The rest of the blast-furnace bullion, approximately 80%, is lead bullion, and it is assumed that all this lead is retained as final product. The emission factor is calculated as follows. Mid-points of the ranges are used in making the calculation.

$$\frac{\text{lb. dust from reverb.}}{\text{ton Pb produced}} = \frac{\text{lb. dust}}{\text{ton dross}} \times \frac{\text{tons dross}}{\text{ton bl.-furn.}} \times \frac{\text{tons bl.-furn. bulk}}{\text{ton Pb produced}}$$

$$= 80 \quad \times 0.2 \quad \times \frac{1}{0.8}$$

$$= 20 \text{ lb. dust from reverberatory furnaces per ton of lead produced}$$

Estimate of the quantity of particulate emissions from dross reverberatory furnaces is as follows.

$$E = (467,000)\left(\frac{20}{2,000}\right)(1-0.50) = 2,330 \text{ tons}$$

4.10.4.5 Materials Handling: The emission factor for materials handling in lead smelting is set in relation to the factors set for this source in the copper and zinc industries. Since the ratio of ore consumed to metal obtained is lower than for zinc and copper, the emission factor assumed for the lead industry is the lowest of the three. A factor of 5 lb. dust per ton of lead produced is used. The amount of dust from materials handling is estimated as follows.

$$E = (467,000)\left(\frac{5}{2,000}\right)(1-0.90\text{x}0.35) = 800 \text{ tons}$$

REFERENCE LIST

PRIMARY NONFERROUS METALS

1. Private communications, industrial sources.

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3. "Air Pollutant Emission Factors," Report of the National Air Pollution Control Administration, Washington, D.C., pp. 7-26, April 1970.

4. "Systems Study for Control of Emissions, Primary Nonferrous Smelting Industry," Report of the National Air Pollution Control Administration, Cincinnati, Ohio, June 1969.

5. Private communication, Office of Air Quality Control, Washington State Department of Health, Seattle, Washington.

6. Private communication, Division of Air Pollution Control, Arizona State Health Department.

7. Kirk and Othmer, Encyclopedia of Chemical Technology, First Edition, John Wiley and Sons, New York, Vol. 15, 1956.

8. Private communication, industrial source.

9. 1968 Minerals Yearbook, Vol. I-II, Metals, Minerals, and Fuels, U.S. Department of the Interior, Bureau of Mines, 1969.

10. D. M. Liddel, Handbook of Nonferrous Metallurgy, McGraw-Hill, Second Edition, p. 448, 1945.

11. Stern, A. C., Air Pollution, Vol. III, Academic Press, New York, p. 179, 1968.

4.11 Fertilizer and Phosphate Rock

Because of the close industrial connection between phosphate rock and fertilizer, these two industries are considered together. Approximately 50% of phosphate rock is used in fertilizer manufacture in this country. One third is exported.

A summary of emission factors and estimated emissions is given in Table 4.11-1. Information and data on emissions were found for the following: dryers, grinders and calciners used in beneficiation of phosphate rock; evaporators and prilling towers used in the manufacture of ammonium nitrate; rock pulverizers and acid digesters used in the manufacture of wet-process phosphoric acid; dryers, coolers, and granulators used in granulation of phosphate fertilizers; and machines for bagging fertilizer. No information or data on emissions were found for the following: dryers and coolers used in the manufacture of ammonium nitrate and urea; prilling towers used in the manufacture of urea; screens and mills used in the manufacture of phosphate fertilizers; crystallizers and dryers used in the manufacture of ammonium sulfate; and materials handling equipment in general. Values of C_c and C_t are discussed in Chapter 5, pp. 230-231.

4.11.1 Phosphate Rock

Phosphate rock is mined mostly as a strip-mining operation; and in Florida, where approximately 75% of phosphate rock is produced, much of the stripping is a dredging of underwater deposits. Sources of particulate air pollution are drying and grinding of the washed rock, and calcining to remove organic material and reduce carbonate content. The amount of phosphate rock which may be produced on the premises of fertilizer plants, and which might therefore be attributable to fertilizer production is not known, and no attempt is made to estimate it. The dust emissions estimated under this heading are those from drying and grinding of the rock wherever they may arise. However, the rock used in fertilizer manufacture is assumed to undergo a final pulverizing in a roller mill at the fertilizer plant, and the dust from this grinding is attributed to fertilizer manufacture.

The emission factor for dryers is estimated from data furnished by air pollution control agencies. Five emission factors, ranging from 1.4 to 260 lb. dust discharged from the dryer per ton of rock produced, have a geometric mean of 12 lb/ton. These factors, which are calculated from stack samples on effluent streams from control equipment and reported efficiencies of the equipment, are tabulated here.

TABLE 4.11-1

PARTICULATE EMISSIONS
PHOSPHATE ROCK AND MANUFACTURE OF FERTILIZER

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/yr)
I. Phosphate Rock	41,300,000 tons per year					
A. Dryer		12 lb/ton of end product	0.94	1.0	0.94	14,000
B. Grinder		2 lb/ton of end product	0.97	1.0	0.97	1,000
C. Materials handling		2 lb/ton of end product	0.90*	0.25*	0.22	30,000
D. Calcining		40 lb/ton of end product	0.95	1.0	0.95	8,000
II. Ammonium Nitrate	2,800,000 tons of NH_4NO_3 granules					
A. Evaporator		1 lb/ton of end product				
B. Prilling tower		12 lb/ton of end product				
C. Dryer and cooler						
D. Materials handling						
1. Elevators						
a. boots						
b. heads						
2. Conveyors						
a. transfer points						
b. discharge to bins, silos						
3. Shipment of product						
a. bagging		1 lb/ton (controlled)				
b. bulk loading						
	Total for Ammonium Nitrate	Assume 1% of end product				28,000
III. Urea--same as Ammonium Nitrate	1,000,000 tons of $(NH_4)_2CO$ granules	Assume 1% of product				10,000
IV. Phosphate Fertilizers						
A. Rock pulverizing	17,000,000 tons of phosphate rock	6 lb/ton of rock	0.80	1.0	0.80	10,000
B. Fluoride particulate from acid-rock reaction	4,370,000 tons of P_2O_5 from phosphate rock	48 lb. partic./ton of P_2O_5	0.95	0.95	0.90	9,000
1. Wet-process reactor						
2. Filter						
3. Mixers superphosphate manufacture						
C. Pre-neutralizer						
D. Granulating equipment	18,000,000 tons of granular material					
1. Blunger						
2. Granulator		0.5 lb/ton				
E. Dryer		105				
F. Cooler		90 lb/ton				
		195	0.95	0.95	0.90	169,000
G. Screens						
H. Mills						
I. Materials Handling						
1. Unloading of raw-material shipments						
a. phosphate rock						
b. potash						
2. Conveyors						
a. transfer points						
b. discharge to bins, silos						
3. Elevators						
a. boots						
b. heads						
		2 lb/ton of granular material				18,000
4. Shipment of product						
a. bagging machines	50% of 18,000,000 tons	1 lb/ton (controlled)				4,000
b. bulk loading						
V. Ammonium Sulfate	2,700,000 tons	1% of product*				27,000
A. Crystallizer						
B. Drying						
C. Shipping						
1. Bagging machines						
2. Bulk loading						
	Total for Phosphate Rock and Fertilizer					328,000

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* Assumed.

Emission Factors for Dryers (lb. dust per ton of rock produced)

1.4
3.5
10.0
16.0
260.0

The quantity of particulate emissions from dryers is calculated as follows:

P = 41,300,000 tons phosphate rock produced per year (1968)
e_f = 12 lb. dust discharged from the dryer per ton of rock produced
C_c = 94%, average operating efficiency of particulate control equipment on dryers
C_t = 100%, percent of rock production for which particulate control equipment is installed on dryers

$$E = \frac{(41,000,000)(12)(1-0.94 \times 1.00)}{2,000} = 14,000 \text{ tons/yr from dryers}$$

Data for emissions from dust collectors on dryers (Florida) show the same wide dispersion that has been found in other industries. The arithmetic mean for 38 items of data is 0.49 lb. of dust per ton of rock; the geometric mean is 0.30 lb/ton. The range is 0.02 to 2.2 lb/ton. Table 4.11-2 gives statistical calculations for data on dryers.

TABLE 4.11-2

STATISTICAL CALCULATIONS
PARTICULATE EMISSIONS FROM PHOSPHATE ROCK DRYERS
Discharge from Control Equipment

Number of Items	38
Arithmetic Mean	0.49 lb. dust/ton of product
Geometric Mean	0.30
Median	0.25
Range	0.02-2.20
Standard Deviation	0.52
Standard Error of the Mean	0.08
Coefficient of Variation	1.06

Particulate emissions discharged to the atmosphere from dryers are estimated from the above data as follows:

$$E = 41{,}300{,}000 \times \frac{0.3}{2{,}000} = 6{,}000 \text{ tons of particulate per year}$$

from drying phosphate rock

The emission factor for grinders is based on only two data items, 1.7 and 2.0 lb. dust per ton of rock produced. Calculation of the emissions is as follows:

P = 41,300,000 tons rock per year
e_f = 2 lb. of dust per ton of particulate
C_c = 97%, average operating efficiency of dust collectors on grinders
C_t = 100%, percent of rock production for which dust collectors are installed on grinders

$$E = \frac{(41{,}300{,}000)(2)(1-0.97 \times 1.0)}{2{,}000} = 1{,}200 \text{ tons dust per year}$$

from grinders

Data from Florida, where baghouses are used to collect dust from grinders, show an average of 0.05 ton of dust discharged to the atmosphere per ton of rock produced. Calculation with this factor produces an estimate of 1,000 tons of dust per year--unusually good agreement.

Materials handling losses at conveyor transfer points, conveyor discharge into bins, loading of rock shipments, etc., are estimated at 2 lb/ton[15] of rock produced as an average for the industry. Many of these points in some plants will have dust-collection systems. It is assumed that 25% of these sources are controlled with an average efficiency of 90%. The resulting estimate is 30,000 tons/yr of dust lost by the industry in materials handling.

An emission factor for calcining is estimated from data in Reference 1. Mentioned is an emission rate of 33.7 tons/day. Listed capacity of the plant[2] is 1,000,000 tons of processed rock per year; the number of roasters is three. If it be assumed that the calciner involved, a new fluid-bed roaster which is the largest of the three, processes half the calcined plant output and that the plant operates 300 days/year, the following calculation is made for an emission factor.

$$33.7 \text{ tons dust/day} \times 300 \text{ days/yr} \times \frac{1 \text{ yr.}}{10^6 \times 0.5 \text{ tons rock}} \times 2{,}000 \text{ lb/ton}$$

$$= 40.4 \text{ lb. dust from the calciner per ton of rock}$$

This factor is much lower than those for fluid-bed roasters used in non-ferrous smelting. Western phosphate rock is generally comparatively high in organic content, and calcining is a frequent operation in processing. Western rock accounts for approximately 15% of national production. Calcining of rock in the southeastern part of the country is of less importance, but some calcining is done. If we assume that 20% of total production is calcined, the following estimate of dust from calcining is obtained.

P = 20% of 41,300,000 tons/yr
e_f = 40 lb. of dust/ton of end product
C_c = 95%, average operating efficiency of dust collectors on calciners
C_t = 100%, percent of calcining capacity on which dust collectors are installed

$$E = \frac{(0.20 \times 41{,}300{,}000)(40)(1-0.95 \times 1.00)}{2{,}000} = 8{,}000 \text{ tons of}$$

particulate per year discharged to the atmosphere from calcining phosphate rock

4.11.2 Fertilizer

Particulate air pollution from fertilizer manufacture is mainly from drying and cooling of granular material. In the manufacture of phosphate fertilizers, drying is done in horizontal, rotary equipment. In the manufacture of ammonium nitrate and urea, prilling towers are used. In the manufacture of ammonium sulfate, air-blowing is utilized to control size and shape of crystals. Dust is generated also in screening and transport of material and in handling for shipment.

4.11.2.1 Ammonium Nitrate and Urea: In the manufacture of ammonium nitrate and urea, over 95% is produced by prilling. No data have been published on particulate emissions from these plants; however, results of recent stack-sampling tests[3] show an emission rate from prilling towers of 1 lb. dust/ton of ammonium nitrate produced and from dryers, 12 lb/ton. To estimate the particulate emissions from these industries, an emission factor of 1% of end product is used.[4] Tonnages of granular ammonium nitrate and urea were 2,826,000 and 1,000,000, respectively, in 1968.[5] The particulate emissions from ammonium nitrate are estimated at 28,000 tons and from urea at 10,000 tons.

4.11.2.2 Phosphate: Particulate emissions from the manufacture of phosphate fertilizer come from pulverizing of rock and from chemical reaction between rock and acid as well as from drying and cooling the granular product. Particulate from reaction between phosphate rock and acid is a mist of dilute fluosilicic acid. In drying and cooling little variation in quantity and nature of dust is likely as long as the basic materials are the same; however, change in type of rock in superphosphate manufacture, for example, can noticeably affect the amount of dust generated.[6]

4.11.2.2.1 Rock pulverizing: For particulate emissions from the pulverizing of phosphate rock, it is assumed that all rock used in fertilizer manufacture undergoes a pulverizing at the fertilizer plants. Pulverized rock is transported by pneumatic conveying, and the air in the system is recirculated. The recirculated air must be vented to prevent accumulation of moisture; the vent stream is passed through a cyclone. Dust from the cyclone has been measured at approximately 24 lb/hr from two roller mills pulverizing 20 tons of rock/hr.[7] The emission factor on a weight basis is 1.2 lb. dust/ton of phosphate rock pulverized. Table 4.11-3 shows the amount of phosphate rock used for fertilizer manufacture in 1968.[8]

TABLE 4.11-3

USE OF PHOSPHATE ROCK IN FERTILIZER MANUFACTURE, 1968

Process	Total Used in Fertilizer Mfg.
H_3PO_4, wet process	9,500,000 tons
Ordinary superphosphate	3,700,000
Triple superphosphate	3,900,000
Total	17,000,000

Estimation of the amount of particulate pollutants from pulverizing phosphate rock is as follows:

$$E = (17{,}000{,}000)\left(\frac{1.2}{2{,}000}\right) = 10{,}000 \text{ tons/yr of dust from rock ground in pulverizers}$$

If we assume that the efficiency of the cyclones on the vent lines is 80% and that all pulverizing and pneumatic conveying installations are equipped with cyclones, the source emission factor would be 6 lb. dust/ton of rock pulverized.

4.11.2.2.2 Wet-process phosphoric acid and superphosphate: Air pollution studies of the manufacture of wet-process phosphoric acid have been mostly concerned with emissions as fluoride; data on amount of particulate matter emitted are lacking. Particulate is formed by reaction between hydrogen fluoride and silica, which is present apparently as silicate. Hydrogen fluoride is produced by reaction between fluoride in the rock and sulfuric acid. There are several reactions possible between hydrogen fluoride, silica, and water[9]; but the most important at the temperature and concentrations of the wet process are the following:

$$CaF_2 + H_2SO_4 \longrightarrow CaSO_4 + 2HF$$

$$4HF + SiO_2 \longrightarrow SiF_4 + 2H_2O$$

$$3SiF_4 + 2H_2O \longrightarrow 2H_2SiF_6 + SiO_2$$

The first two reactions take place in the digesters; the third takes place in water present as fine droplets in the ducts and launders which conduct the effluent gas stream from the digesters. The product of the last reaction is a mist of dilute fluosilicic acid together with silica as a very finely divided precipitate.[10] Agglomeration causes the formation of a flaky material which settles on exposed surfaces. Data in Reference 11 indicate that approximately 10 lb. of fluoride ion is discharged from a digester system per ton of P_2O_5 produced. The following data are listed for venting a digester system with a nominal capacity of 300 tons of P_2O_5 per day:

Volume, cu ft/min	15,000
Temperature, °F	130-160
Fluoride conc., mgm/cu ft	33-100

An average of 60 mgm/cu ft is assumed.

$$15{,}000\ \frac{\text{cu. ft.}}{\text{min.}} \times \frac{60\ \text{mgm.}}{\text{cu. ft.}} \times \frac{1\ \text{lb.}}{453{,}000\ \text{mgm.}} \times \frac{1440\ \text{min.}}{\text{day}} \times \frac{1\ \text{day}}{300\ \text{ton}\ P_2O_5}$$

$$= 9.55\ \text{lb.}\ F^-\ \text{from digester system per ton of}\ P_2O_5\ \text{produced}$$

Ten pounds of fluoride ion per ton of P_2O_5 is only about 5% of the fluoride ion actually produced. The other 95% remains dissolved in the acid as it flows from the digesters and escapes at various points in the process stream. The theoretical yield from phosphate rock is 178 lb. of fluoride ion per ton of P_2O_5.

The particulate matter which forms from fluoride ion has been determined for a continuous superphosphate "den."[10] The following composition is listed.

H_2SiF_6	25 parts by weight
SiO_2	5
H_2O	70

The product from reaction between acid and phosphate rock in the wet-process manufacture of phosphoric acid is of different characteristic than the product in the manufacture of superphosphate. The product in the wet-process manufacture of acid is a slurry; the product in the manufacture of superphosphate is a much drier material that begins to set up as soon as it is discharged from the mixer. However, with the following assumptions, an estimate of the amount of fluoride particulate discharged from the manufacture of phosphates can be calculated.

1. Assume that the composition of fluoride particulate listed above for a superphosphate "den" is typical of particulate from all acid-rock reactions.

2. Assume that the amount of fluoride (5%) combining to form particulate in the effluent gas stream from a digester system for wet-process acid is representative of the percent of fluoride from the manufacture of superphosphates which forms particulate. An emission factor for fluoride particulate is then:

$$\frac{\text{lb. particulate}}{\text{ton } P_2O_5} = \frac{\text{lb. } F^- \text{ to } H_2SiF_6}{\text{ton } P_2O_5} \times \frac{\text{lb. } H_2Si_6}{\text{lb. } F^-} \times \frac{\text{lb. part.}}{\text{lb. } H_2SiF_6}$$

$$= (9.55)\left(\frac{144}{114}\right)\left(\frac{100}{25}\right) = 48.1 \text{ lb. particulate per ton of } P_2O_5$$

produced from reaction of acid and phosphate rock,
for both wet-process acid and superphosphates

In 1968, 4,149,000 tons of P_2O_5 were produced as phosphatic fertilizer. If we assume that 95% of P_2O_5 produced is actually made into fertilizer, the tonnage of P_2O_5 produced in reaction between acid and rock was 4,370,000. Estimate of the tonnage of fluoride particulate discharged to the atmosphere is then:

P = 4,370,000 tons/yr of P_2O_5 produced in the manufacture of phosphatic fertilizer
e_f = 48 lb. of fluoride particulate per ton of P_2O_5 produced
C_c = 95%, average operating efficiency of fluoride scrubbers
C_t = 95%, percent of production capacity of phosphatic-fertilizer industry that is equipped with fluoride scrubbers

$$E = \frac{(4,370,000)(48)(1-0.95 \times 0.95)}{2,000} = 9,440 \text{ tons/yr of fluoride}$$

particulate from the manufacture of phosphatic fertilizers.

Comparison of this calculation can be made with data from the State of Florida, where the citrus industry necessitates strict control of fluoride emissions. Data from both company reports and state reports show a geometric mean of 0.12 lb. fluoride ion per ton of P_2O_5 produced in the manufacture of triple superphosphate.[12] Calculation of this emission factor assumes that production was at listed capacity at the time of testing. This estimate is from 25 items of data on triple superphosphate plants which range from 0.01 to 1.56 lb. of F^- per ton of P_2O_5 produced. To the extent that production was below listed capacity, the emission factor would be larger. The emission data are reported on a time basis, lb. F^- per hr.; the capacities are listed as tons per day. Twenty-four data items for wet-process phosphoric acid plants have a geometric mean of 0.04 lb. F^- per ton of P_2O_5; the range of these data is 0.003 to 0.377 lb. F^- per ton of P_2O_5. The following calculations estimate the amount of fluoride particulate for national production with control measures equal to those in Florida. We assume that the emission factor for manufacture of normal superphosphate is the same as for triple superphosphate. Production figures are from Reference 2.

Normal and concentrated superphosphate

$$\frac{2{,}300{,}000 \text{ tons } P_2O_5^{\underline{13/}}}{\text{yr.}} \times \frac{0.12 \text{ lb. } F^-}{\text{ton } P_2O_5} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = \frac{138 \text{ tons } F^-}{\text{yr.}}$$

Wet-process $H_3PO_4^{\underline{13/}}$

$$\frac{3{,}860{,}000 \text{ tons } P_2O_5}{\text{yr.}} \times \frac{0.04 \text{ lb. } F^-}{\text{ton } P_2O_5} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = \frac{733 \text{ tons } F^-}{\text{yr.}}$$

$(773 + 138)\left(\frac{144}{114}\right)\left(\frac{100}{25}\right) = 4{,}600$ tons of fluoride particulate per year

4.11.2.2.3 Granulation: Dust from granulation is mainly from dryers and coolers. Dust from screens, hammermills, and materials handling is not insignificant since the granulation process involves recirculation of material to build up the size of granules. The manufacture of salt grades (fertilizers containing potash) produces a fume of NH_4Cl which is composed of particles less than 5 microns and is difficult to collect. The amount of chloride fume produced depends on the raw materials used. Use of ammoniating solutions and sulfuric acid tend to increase the amount of fume.

Published data on emissions from granulation processes are meager and not definitive in every instance of what process equipment is being vented. A typical dust-collection system in a granulation plant will have two or more cyclones with a scrubber for each. One cyclone and scrubber will serve the dryer, the other will serve the cooler, screens, elevators, hammermills, etc. Discharge from the scrubbers may be into a plenum chamber with a single stack for discharge to the atmosphere. A stack sample of the emissions to the atmosphere may thus include a dryer, a cooler, and such other dust sources as are connected to the dust-collection system. An emission factor for emissions from granulation is obtained from data averaged for 15 plants over the country.[14] The averages, which are pounds of dust discharged from the process equipment, are listed here.

ammoniators	0.53	lb. of dust per ton of fertilizer
dryers	105.0	
coolers	90.0	
Total for granulation	195.53	

Calculation of the particulate emissions to the atmosphere from granulation is as follows. No attempt is made to account for variation in emissions with variation in materials used in the granulating process.

Total tonnage of granulated fertilizer:

Amm. phosphate--1,640,000 tons as P_2O_5 at 40% =	4,000,000 tons
Salt grades--205,000 tons as P_2O_5 at 21% =	975,000
Solid fertilizer (SIC No. 2872, plants which do not manufacture any of their raw materials)	7,200,000
	12,175,000
Normal superphos--914,000 tons as P_2O_5 at 19%	4,810,000
Triple superphos--1,389,000 tons as P_2O_5 at 45%	3,080,000
	7,890,000
Assume 75% of superphosphates are granulated	5,918,000
	18,093,000

P = 18,100,000 tons per year (1968), tonnage of granular material

e_f = 195 lb. of dust per ton of fertilizer

C_c = 95%, average operating efficiency of dust-collection equipment in granulation plants. (Assumes cyclone and wet scrubber.)

C_t = 95%, percent of granulation production capacity on which dust-collection systems are installed.

$$E = \frac{(18,100,000)(195)(1-0.95 \times 0.95)}{2,000} = 169,000 \text{ tons of dust per}$$

year discharged to the atmosphere from granulation

To check this calculation, an arithmetic average of 7.2 lb. dust per ton of fertilizer was obtained from 13 items of data from various literature sources and state agencies for discharge to the atmosphere from dust-collection equipment on granulation plants. The range of these data is 0.13 to 17.2 lb/ton. The arithmetic average is used since values are distributed more or less evenly over the range. The particulate emissions for the industry calculated with this factor are as follows:

$$(18{,}100{,}000)\left(\frac{7.2}{2{,}000}\right) = 65{,}000 \text{ tons of particulate per year from granulation}$$

Since the data used in this estimate are mostly from plants in locales in which extensive effort is being made at controlling air pollution, the figure is considered to represent a potential level of particulate emissions which could be achieved.

Dust from bagging operations has been measured in two stack samples as 1.1 and 0.9 lb. dust per ton. Assumption is made that 50% of granular production is bagged.

Dust losses from loading bulk material, unloading of phosphate rock and potash, at conveyor transfer points, etc., are estimated at 2 lb. per ton of granulated material.[15]

4.11.2.3 Ammonium Sulfate: Ammonium sulfate is mainly a by-product. Its manufacture involves crystallizing and drying of the crystals. Air-blowing into the crystallizer is used to control the size and shape of the crystals.[16] The crystallizer and the dryer are sources of particulate pollution. No data have been found on emission factors for the manufacture of ammonium sulfate. The assumed factor is 1% of the end product.

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4.12 Asphalt

Asphalt is a raw material for several industries. Two of the more important with regard to air pollution are hot mix asphalt for paving and the manufacture of roofing materials. Asphalt used in the roofing industry is "blown" to improve its resistance to softening, and approximately 50% of this asphalt is blown at those roofing plants which are remotely located from the source of supply. Plants close to their source of supply obtain blown asphalt from the refineries. In the manufacture of asphalt roofing, the particulate pollutant is a hydrocarbon mist; and the main source of particulate emissions is the saturator in which fibrous-base material is impregnated with hot asphalt. In the mixing of materials for asphalt paving, the pollutant is dust; the main source of emissions is the dryer for the stone aggregate. Elevators, screens, storage bins and weigh hoppers are also sources of dust emissions in hot-mix plants.

Emission factors and estimated emissions are summarized in Table 4.12-1. Data on emissions were found for all the sources listed. These are: asphalt blowers; asphalt saturators used in the manufacture of asphalt roofing materials; aggregate dryers used in asphalt paving plants; and the bins weigh hoppers, etc., which are part of asphalt paving plants. Values of C_c and C_t used in the calculations are discussed in Chapter 5, pp. 231-232.

The production of asphalt and its use in the two industries in 1968 is estimated as follows.

Asphalt from refineries--136,000,000 bbl. (5.5 bbl. per ton)[1]

or

$$\frac{136{,}000{,}000}{5.5} = 24{,}700{,}000 \text{ tons asphalt}$$

Production by the asphalt-roofing industry[1]
Roofing--77,984,000 sales squares at 234 lb/sales square
Siding--422,000 sales squares at 175 lb/sales square
Saturated felts--843,000 tons

The weight of the asphalt in these materials is calculated as follows:[2]

Roofing--Asphalt roofing is 170% saturated with asphalt, i.e., asphalt in the material weighs 1.70 times as much as the material bound by the asphalt.

TABLE 4.12-1

PARTICULATE EMISSIONS
ASPHALT

Source	Quantity of Material	Emission Factor	Efficiency of Control (C_c)	Application of Control (C_t)	Net Control ($C_c \cdot C_t$)	Emission (tons/yr)
I. Asphalt Roofing	6,264,000 tons/year					
A. Blowing	(asphalt used in	4 lb/ton			0.50	3,000
B. Saturator	roofing manufacturer)	4 (controlled)			--	14,000
II. Hot-Mix Paving Plants	251,000,000 tons/year (hot-mix asphalt)					
A. Dryer		32*				
B. Bins, weigh		8				
hopper, etc.		40	0.97	0.99	0.96	201,000
		Total for Primary Users of Asphalt				218,000

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* Prior to any control equipment.

$$1 + 1.7 = 2.7$$

$$\frac{1.7}{2.7} \times 100 = 63.0\% \text{ asphalt}$$

Saturated felts--Saturated felts are 140% saturated.

$$1 + 1.4 = 2.4$$

$$\frac{1.4}{2.4} \times 100 = 58.4\% \text{ asphalt}$$

Siding--estimated at 60% asphalt.

Therefore, the amount of asphalt used is shown below.

roofing:	$77{,}984{,}000 \times 234 \times 0.63 \times \frac{1}{2{,}000} =$	5,750,000 tons
siding:	$422{,}000 \times 175 \times 0.60 \times \frac{1}{2{,}000} =$	22,000 tons
saturated felt:	$843{,}000 \times 0.584 =$	492,000 tons
total		6,264,000 tons

The amount of asphalt used in paving is calculated as the difference of 24,700,000 and 6,264,000 or 18,436,000 tons.

4.12.1 Asphalt Roofing

The emissions from the manufacture of asphalt roofing are calculated as follows. For the blowing of asphalt, the factor used is 3.9 lb. particulate per ton of asphalt.[3] This is the only value found in the literature.

$$6{,}264{,}000 \times 0.50 \times \frac{3.9}{2{,}000} = 6{,}100 \text{ tons/yr, particulate discharged from blowing of asphalt.}$$

Data on control of emissions from asphalt blowing have not been obtained, but it is estimated that 50% of the particulate emissions from asphalt blowing in the roofing industry escape to the atmosphere.

The emission factor for the saturator is calculated as follows. Emission rates on a time basis are tabulated from Reference 4.

Inlet to Control Equipment	Control Equipment	Outlet from Control Equipment
67.7 lb/hr	Cycl., bag filter	25.5 lb/hr
55.0	Scrubber	7.7
71.4	Scr., Lo-volt, ESP	10.0

The average of the rates into the control equipment is approximately 65 lb/hr; the average of the emissions from the control equipment is 14.3 lb/hr.

Assume the average rate of felt speed to the saturator is 12 squares per minute.[2]

1 felt square = 100 sq. ft.

Assume an average weight of felt of 27 lb. per 480 sq. ft. (27 lb. felt). Assume an average saturation of 160%.

$$\frac{\text{lb. partic.}}{\text{ton of asphalt}} = \frac{\text{65 lb. partic.}}{\text{hr.}} \times \frac{\text{1 min.}}{\text{12 squares}} \times \frac{\text{1 square}}{\text{100 sq. ft.}} \times \frac{\text{480 sq. ft.}}{\text{27 lb. felt}}$$

$$\times \frac{\text{1 lb. felt}}{\text{1.60 lb. asphalt}} \times \frac{\text{2,000 lb.}}{\text{ton}} \times \frac{\text{1 hr.}}{\text{60 min.}}$$

= 20.1 lb. partic. per ton of asphalt applied

The amount of particulate from asphalt saturators is calculated as follows:

$$\frac{\text{lb. partic. to atm.}}{\text{yr.}} = \frac{\text{14.3 lb. partic. to atm.}}{\text{65 lb. partic. to scr.}} \times \frac{\text{20.1 lb. partic. to scr.}}{\text{ton of asphalt used}}$$

$$\times \frac{\text{6,264,000 tons asphalt used}}{\text{yr.}}$$

= 13,500 tons of particulate per year emitted from asphalt saturators

4.12.2 Hot-Mix Asphalt

Dust from plants for mixing asphalt paving is collected in two effluent streams. One is from the dryer; and the other is from the bins, screens, elevators, and weigh hoppers, or any part of these. Emissions from dryers were calculated from 12 items of data to have a geometric mean of 32 lb. of dust generated per ton of asphalt produced.[4,5] Eleven of these items range from 9.3 to 71 lb. per ton. The twelfth item is 390 lb. per ton. Only two sets of data were available for dust collected from bins, weigh hopper, etc. These are 11 and 4.3 lb. per ton, and the arithmetic average is used, 7.6 lb. dust per ton of asphalt generated in the plant exclusive of the dryer. Thus the total is 40 lb. per ton.

Calculation of amount of dust from asphalt plants is as follows.

P = 251,000,000 tons of hot-mix asphalt per year

e_f = 40 lb. of dust per ton of hot-mix produced

C_c = 97%, average operating efficiency of dust-collection systems installed on hot-mix plants

C_t = 99%, percent of production capacity in the industry on which dust collectors are installed.

$$E = \frac{(251{,}000{,}000)(40)(1-0.97 \times 0.99)}{2{,}000} = 201{,}000 \text{ tons per year,}$$

dust discharged to the atmosphere from hot-mix paving plants

Data on emissions to the atmosphere range from 0.06 to 21.4 lb. per ton for 59 data items obtained from air pollution control agencies and industrial sources. In the plant mentioned above with the loading of 390 lb. per ton from the dryer, the emission to the atmosphere was measured as 0.13 lb. per ton. Much of these data are from agencies in areas where intensive effort at control is being made, and for this reason the emission rate calculated from these data is not realistic, nationwide. The arithmetic mean is 1.3 lb. dust emitted to the atmosphere per ton of asphalt mixed; the geometric mean is 0.45 lb. per ton. The geometric mean approximates the median, 0.42 lb. per ton. If air pollution from the entire industry were controlled to this extent, the particulate emissions discharged to the atmosphere would be estimated as follows.

$$E = (251{,}000{,}000)\ \frac{0.4}{2{,}000} = 50{,}200 \text{ tons per year}$$

The statistical data are shown in Table 4.12-2. Figure 4.12-1 shows the frequency distribution of the 59 data items. All these data are from plants with some type of dust-collection equipment installed in addition to the pre-cleaner.

TABLE 4.12-2

STATISTICAL CALCULATIONS PARTICULATE EMISSIONS TO THE ATMOSPHERE FROM CONTROLLED ASPHALT PLANTS

Number of data items	59
Arithmetic mean	1.29 lb/ton
Median	0.42 lb/ton
Range	0.06-21.4 lb/ton
Standard deviation	3.42
Standard error of the mean	0.44
Coefficient of variation	2.67
Geometric mean	16/ton

There is no distinction in these calculations between batch plants and continuous plants or as to type of control equipment. Also, there is no indication for most of the data of the water-to-gas ratio in the scrubbers. Variations in this ratio might be a significant cause of the wide dispersion of the data. Gas velocity through the dryer is also an operating variable with a decided effect on dust emission.

The data described herein for discharge from scrubbers (emissions to the atmosphere) provide a higher emission factor than those listed in AP-42, "Compilations of Air Pollutant Emission Factors".[6] The factor, 0.40 lb. per ton, is approximately twice the value listed in AP-42, 0.2 lb. per ton for both multiple centrifugal scrubbers and baffle spray towers. Much of the data obtained for this report was from plants with a "scrubber" listed, but the type was not mentioned. Of the 59 items of data, 42 from plants with some type of scrubber had emission factors above 0.2 lb. per ton. One consideration in explaining the difference might be the difference that exists in code regulations in areas from which the data were obtained.

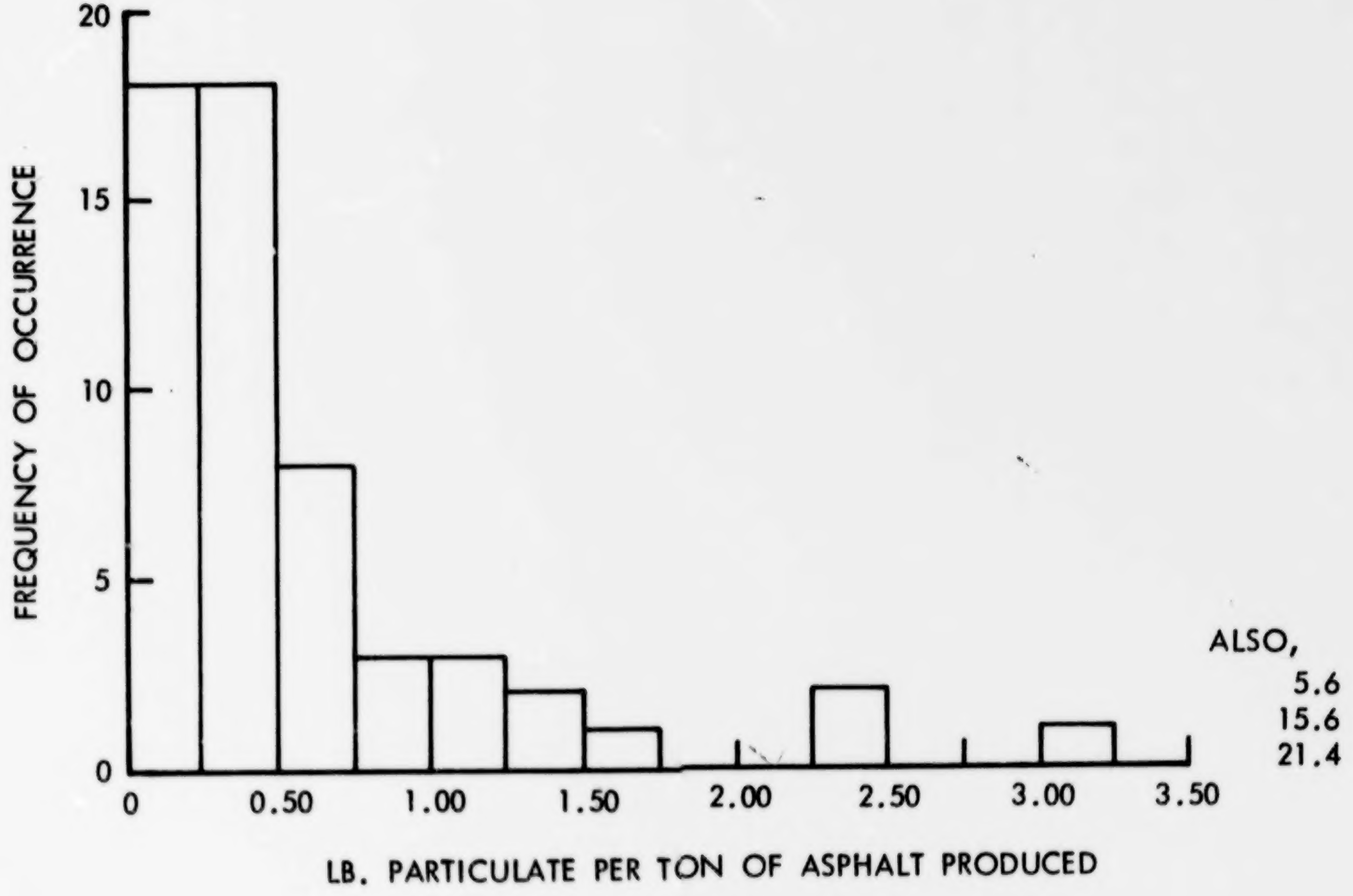

Figure 4.12-1 - Frequency Distribution (emission factors for asphalt plants - particulate discharged from dust collectors to the atmosphere)

REFERENCES

ASPHALT

1. Statistical Abstracts, 1969, Bureau of the Census, U.S. Department of Commerce, Table No. 1137.

2. Greenfeld, S. H., "A Study of the Variables in the Saturating of Roofing Felts," U.S. Department of Commerce, Bureau of Standards; Building Science Series 19, June 1969, p. 1.

3. Von Lehnden, D. J., R. P. Hangebrauck and J. E. Meeker, "Polynuclear Hydrocarbon Emissions from Selected Industrial Processes," Journal of the Air Pollution Control Association, **15**, (7), 306-312, 1965.

4. "Air Pollution Engineering Manual," Public Health Service Publication No. 999-AP-40, 1967, pp. 378-383.

5. Private communication, industrial source.

6. Duprey, R. L., "Compilation of Air Pollutant Emission Factors," Public Health Service Publication No. 999-AP-42, 1968, p. 34.

4.13 Ferroalloys

The production of ferroalloys has many dust or fume producing steps. Particulates are emitted from raw material handling, mix delivery, crushing, grinding, and sizing, and furnace operations. The dust resulting from the solids handling steps does not present a difficult control problem. Emissions from furnaces vary widely in type and quantity, depending upon the particular ferroalloy being produced, type of furnace used, and the amount of carbon in the alloy.

There are four major methods used to produce ferroalloy and high purity metallic additives. These are: (1) blast furnace, (2) electric-arc furnace, (3) alumino-silicothermic process, and (4) electrolytic deposition. The blast furnace and electric-arc furnaces are the major sources of particulates, and they are discussed in more detail in the next section.

4.13.1 Blast Furnaces

Ferromanganese is produced in blast furnaces by carbon reduction of manganese ore and iron ore in the presence of coke and limestone. Only two items of data were found regarding emission factors from these furnaces. Reference 1 reported that the emissions from two 350-ton ferromanganese furnaces averaged about 125 tons of dust per day. Assuming that the dust emitted from each furnace accounted for half the total, an emission factor of 356 lb/ton was calculated for these furnaces. Reference 2 reported the following data on a ferromanganese blast furnace:

Gas volume: 60,000 cfm
Production: 320 tons/day
Outlet grain loading: 12 grains/ft^3

From these data an emission factor of 464 lb/ton was calculated. The arithmetic average of 410 lb/ton was selected for the emission factor for ferromanganese blast furnaces.

All the blast furnaces are equipped with high efficiency dust collection systems because the carbon monoxide in the gas stream is used as a fuel in other parts of the plant. The degree of application of control is, therefore, 1.00 and the efficiency of control is assumed to be 99%.

Total production of ferroalloys by blast furnaces in 1968 was 590,955 tons.[6]

Emissions from blast furnaces were calculated as follows:

$$E = \frac{(591{,}000 \text{ tons/yr})(410 \text{ lb/ton})(1-0.99 \times 1.0)}{2 \times 10^3} = 1{,}210 \text{ tons/yr}$$

Because of the high net control (i.e., 0.99) the emission rates for blast furnaces calculated by the above equation is not too accurate, and a total emission of 1,500 tons/yr will be assumed for this source.

4.13.2 Electric-Arc Furnaces

The submerged arc, or the roof-in open bath, electric furnace can more effectively complete the reduction of the oxides; therefore, higher overall yields of the various metallic components are possible. Also, the electric-arc furnace provides more flexibility and control over the operation than is possible in the coke blast furnace. For these reasons the electric furnace is more often used for the production of ferroalloys.

Emission factors for electric-arc furnaces depend upon the particular ferroalloy being produced. Table 4.13-1 summarizes available emission factor data for electric-arc furnaces.

TABLE 4.13-1

FERROALLOY EMISSION FACTORS

Ferroalloy	Emission Factor (lb of fume/ton of specified product)	Reference
50% FeSi	200	3
"	130	3
"	208	3
"	260	3
75% FeSi	315	3
"	200-400	4
"	315	4
90% FeSi	565	3
"	500	3
"	585	3
"	605	3
Silicon Metal	625	3
"	470-520	5
"	600-700	3
FeMn	45	3
"	22-65	4
SiMn	195	3
"	200	4
"	190	4

Table 4.13-2 lists the arithmetic average of the emission factors for each ferroalloy given in Table 4.13-1.

TABLE 4.13-2

AVERAGE FERROALLOY EMISSION FACTORS

Ferroalloy	Average Emission Factors
50% FeSi	200
75% FeSi	308
90% FeSi	564
Silicon metal	583
FeMn	44
SiMn	195

The factors in Table 4.13-2 are used in subsequent calculations for total emissions from electric-arc furnaces.

A telephone survey of ferroalloy producers was used to determine control practices in this industry (see Section 5, p. 233). The results of the survey for ferroalloy electric furnaces are as follows:

a) Application of control = 49.9%
b) Efficiency of control = 80.5%
c) Net control = 40.2%

Electric-arc furnace production figures (1968) for the various ferroalloys are summarized in Table 4.13-3.

TABLE 4.13-3

FERROALLOY PRODUCTION - ELECTRIC-ARC FURNACES

Ferroalloy	Production (tons)
FeMn	317,421
SiMn	284,499
FeSi	665,383
FeCr and other chrome alloys	389,572
Ferrophosphorus	116,723
Silvery iron	166,181
Silicon metal	96,261
Miscellaneous	84,049

Calculation of particulate emissions from the manufacture of the above ferroalloys is as follows:

1) FeMn

$$E = \frac{(3.17 \times 10^5 \text{ tons/yr})(44 \text{ lb/ton})(1-0.80 \times 0.50)}{2 \times 10^3} = 4,220 \text{ tons}$$

2) SiMn

$$E = \frac{(2.8 \times 10^5)(1.95 \times 10^2)(1-0.80 \times 0.50)}{2 \times 10^3} = 16,500 \text{ tons}$$

3) FeSi

The emission factor used for this calculation is the average of those for the three grades of FeSi listed in Table 4.12-1.

$$E = \frac{(6.65 \times 10^5)(357)(1-0.80 \times 0.50)}{2 \times 10^3} = 71,222 \text{ tons}$$

4) Silicon Metal

$$E = \frac{(9.6 \times 10^4)(583)(1-0.80 \times 0.50)}{2 \times 10^3} = 16,800 \text{ tons}$$

5) Silvery Iron (5-20% FeSi)

An emission factor for silvery iron was not available. However, a factor of 120 lb/ton was determined from extrapolation of data for 50, 75, and 90% FeSi.

$$E = \frac{(1.66 \times 10^5)(120)(1-0.80 \times 0.50)}{2 \times 10^3} = 6,000 \text{ tons}$$

6) Ferrochrome, Ferrophosphorus and Miscellaneous

Emission factors were not available for these alloys. The emission factor for 50% FeSi (200 lb/ton) was assumed applicable.

$$E = \frac{(5.9 \times 10^5)(200)(1-0.80 \times 0.50)}{2 \times 10^3} = 35,400 \text{ tons}$$

Summary of Electric-Arc Furnace Emissions

Ferroalloy	Emissions
FeMn	4,220 tons
SiMn	16,500
FeSi	71,222
Silicon Metal	16,800
Silvery Iron	6,000
Ferrochrome, etc.	35,400
	150,142 tons

4.13.3 Materials Handling

The estimate of the emissions from materials handling is made with the same emission factor used for this source in the Iron and Steel industry--10 lb/ton of metal produced.

$$E = \frac{2{,}704{,}000 \text{ tons} \times 10 \text{ lb/ton} \times (1-0.90 \times 0.35)}{2 \times 10^3} = 9{,}000 \text{ tons}$$

of particulate from handling materials in the manufacture of ferroalloys

Table 4.13-4 summarizes the emission calculations for ferroalloys.

TABLE 4.13-4

PARTICULATE EMISSIONS
PRODUCTION OF FERROALLOYS

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/yr)
I. Furnaces						
A. Blast Furnaces	591,000 tons, ferromanganese	410 lb/ton product*	0.99	1.0	0.99	1,200
B. Electric-Arc Furnaces	317,000 tons, ferromanganese	44 lb/ton	0.80	0.50	0.40	4,200
	285,000 tons, silicomanganese	195 lb/ton	0.80	0.50	0.40	16,500
	665,000 tons, ferrosilicon	357 lb/ton	0.80	0.50	0.40	71,200
	96,000 tons, silicon metal	583 lb/ton	0.80	0.50	0.40	16,800
	166,000 tons, silvery iron	120 lb/ton	0.80	0.50	0.40	6,000
	590,000 tons, ferrochrome, ferrophosphorus	200 lb/ton	0.80	0.50	0.40	35,400
II. Materials Handling	2,710,000 tons of metal produced	10 lb/ton of metal produced	0.90	0.35	0.32	9,000
		Total from Ferroalloys				160,300

---

* All emission factors are "per ton of product."

REFERENCES

FERROALLOYS

1. Specht, S. E., and R. W. Sickles, "New Uses of Electrical Precipitation for Control of Air Pollution," Air Repair, 4(3), 137-140, 1954.

2. Good, C. H., "The Ferromanganese Gas Cleaning Installation at Duquesne Works," Air Repair, 4(4), 173-175, 1955.

3. Private communication, M. McGraw, Air Quality and Emissions Data Division, National Air Pollution Control Administration, Durham, North Carolina, (July 1970).

4. Fredricksen and Nestass, "Pollution Problems by Electric Furnace Ferro-Alloy Production," United Nations Economic Commission for Europe, (September 1968).

5. Gerstle and McGinnity, plant visit memorandum, U.S.D.H.E.W., P.H.S., (June 1967).

6. Minerals Yearbook, Vol. I-II, Bureau of Mines, 1968, p. 506, Table No. 2.

4.14 Iron Foundries

Gray iron foundries range from primitive, unmechanized hand operations to heavily equipped plants in which operators are assisted by electrical, mechanical, and hydraulic equipment. Cupola, electric-arc, electric-induction, and reverberatory air furnaces are used to obtain molten metal for production of castings.

Emission factors and estimated emissions are summarized in Table 4.14-2. Emissions data were found for cupola furnaces, both cold-blast and hot-blast; electric-arc furnaces; handling of sand; core ovens; and shell core machines. No emissions data were found for reverberatory furnaces, electric induction furnaces, casting shake-out systems, grinding and buffing, or materials handling other than sand. Values of C_c and C_t used in the calculations are discussed in Chapter 5, p. 234.

The iron melting process in foundries is the principal source of emissions. Secondary sources include materials handling, casting, shake-out systems, buffing and grinding operations, and core ovens. Cores are baked in ovens which discharge a hydrocarbon mist from the oil in the binder.

Two sources in the literature were used to determine an emission factor for cupolas.[1,2] The data from these two references are separable into classifications, "hot-blast" and "cold-blast" furnaces. Tabulation of the statistics for each classification is shown in Table 4.14-1. The geometric mean of the combined data, 16 lb. particulate/ton of hot metal, is taken as the emission factor.

TABLE 4-14-1

EMISSION FACTORS FOR CUPOLA FURNACES
(lb. particulate/ton hot metal)

	A.P.E. Manual[1]		Engels & Weber[2]		Total		
	Hot-Blast	Cold-Blast	Hot-Blast	Cold-Blast	Hot-Blast	Cold-Blast	Total
No. of Samples	2	5	8	9	10	14	24
Arith. Mean	15	13	14	28	15	23	20
Geom. Mean							16
Median	15	13	12	23	13	20	16
Std. Deviation			10	18	9	17	15
Range	15-16	4-26	7-37	10-73	7-37	4-73	4-73

TABLE 4.14-2

PARTICULATE EMISSIONS

IRON FOUNDRIES

Source		Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions tons/yr
I.	Furnaces	18,000,000 tons of hot metal	15 lb/ton of hot metal	0.80	0.33	0.27	105,000
	A. Cupola						
	1. Hot blast		15 lb/ton of hot metal				
	a. externally fired		--	--	--	--	
	b. recuperative		--	--	--	--	
	2. Cold blast		23 lb/ton of hot metal				
	B. Electric						
	1. Arc		5-10 lb/ton	--	--	--	
	2. Induction		--	--	--	--	
	C. Reverberatory		--	--	--	--	
II.	Materials Handling		*5 lb/ton of hot metal	*0.80	*0.25	*0.20	37,000
	A. Freight Unloading--Coke and Limestone		--	--	--	--	--
	B. Conveyors						
	1. Transfer points		--	--	--	--	--
	2. Discharge to storage		--	--	--	--	--
	a. bins, silos						
	b. stockpiles						
	C. Elevators		--	--	--	--	--
	1. Boots		--	--	--	--	--
	2. Heads		--	--	--	--	--
	D. Sand Handling	10,500,000 tons of sand	0.3 lb/ton of sand	--	--	--	1,000
III.	Core Ovens		0.3 lb/gal of core oil	--	--	--	--
IV.	Shell Core Machines		0.35 lb/ton of cores	--	--	--	--
V.	Casting Shake-out System		--	--	--	--	--
VI.	Grinding and Buffing		--	--	--	--	--
							143,000

---

* Assumed.

The production of iron in foundries for 1968 is tabulated as follows.[3]

Gray iron*	11,577,000 tons
Ductile iron	862,000
Malleable iron	1,039,000
Pressure pipe fittings	1,779,000
Soil pipe and fittings	939,000
	16,196,000

* 3,179,000 tons of ingot molds are included in the tonnage for Gray iron.

The total tonnage is for finished products; this does not include reject castings, gates, runners, sprues, etc., which are part of the hot metal produced. This scrap is assumed to be 10% of the finished product. The total hot metal produced in iron foundries is thus estimated to be:

Finished product	16,400,000 tons
10% as reject, gates, runners, sprues, etc.	1,600,000
Total hot metal	18,000,000

The particulate pollution from furnaces in iron foundries is estimated as follows:

P = 18,000,000 tons of hot metal
e_f = 16 lb. particulate per ton of hot metal produced
C_c = 80%, average collection efficiency of dust collectors installed on furnaces
C_t = 33%, per cent of production capacity of the industry on which dust collectors are installed

$$E = \left(\frac{(18{,}000{,}000)(16)(1-0.80 \times 0.33)}{2{,}000}\right) = 105{,}000 \text{ tons of particulate}$$

pollution discharged to the atmosphere from foundry furnaces in 1968

An estimate has also been made for dust generated in iron foundries by the handling of sand. An emission factor of 0.3 lb. dust per ton of sand is given in Reference 4. The amount of sand used in foundries in 1968 is:[5]

Molding sand	10,300,000 tons
Ground sand	200,000
Total used in foundries	10,500,000

The percent of sand used in iron foundries is estimated from production data in Reference 3. These data indicate that approximately 80% of foundry production, both ferrous and nonferrous, was from iron foundries. We assume the same percentage for use of sand.

$$E = \frac{0.3 \text{ lb. dust}}{\text{ton sand}} \times \frac{10{,}500{,}000 \text{ tons sand}}{2{,}000} \times 0.80 = 1{,}260 \text{ tons of}$$

dust from sand handling

REFERENCES

IRON FOUNDRIES

1. Air Pollution Engineering Manual, Public Health Service Publication No. 999-AP-40; 1967, p. 260.

2. Engels, G., and E. Weber, Cupola Emission Control, translated and published by Gray and Ductile Iron Founders Society, Cleveland, Ohio 1967.

3. "Census of World Casting Production 1967," Modern Casting, December, 1968, pp. 46-47.

4. Duprey, R. L., "Compilation of Air Pollutant Emission Factors," Public Health Service Publication No. 999-AP-12, 1968, p. 29.

5. 1968 Minerals Yearbook, Vol. I-II, Bureau of Mines, Table 1, p. 980, and Table 10, p. 996.

4.15 Secondary Nonferrous Metals

The secondary nonferrous metals industry is considered separately from the primary nonferrous because of the nature of the raw materials and the location of plants. Raw materials for the secondary industry are scrap metal, and residues and skimmings from melting and refining processes. Some of the scrap metal is clean; but much of it contains the various materials, such as rubber, plastic, paint, paper, which are part of scrapped consumer products. Plants for the recovery of scrap metal are located near the most plentiful sources of supply which, for scrap metal, are metropolitan areas.

A summary of emission factors and estimated quantities of emissions is given in Table 4.15-1. Except for burning of insulation from copper wire, fluxing with chlorine in recovery of aluminum and dross processing in aluminum recovery, the sources listed are all furnaces. Emissions data were found for each source except aluminum dross processing, induction furnaces used in aluminum refining and sweating furnaces used in reclaiming copper. Values of C_c and C_t used in the calculations are discussed in Chapter 5, pp. 235-236.

4.15.1 Copper

Operations which are sources of particulate emissions in the recovery of copper and copper alloys may be divided into operations for materials preparation and the smelting and refining operations. These are outlined as follows.

1. Materials preparation
    a. Burning of insulation from wire
    b. Sweating furnaces
    c. Blast furnaces
2. Smelting and refining
    a. Reverberatory furnaces
    b. Rotary furnaces
    c. Crucible furnaces
    d. Electric furnaces

TABLE 4.15-1

PARTICULATE EMISSIONS
SECONDARY NONFERROUS METALS

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emission tons/yr
I. Copper						
A. Materials Preparation						
1. Wire burning	300,000 tons insulated wire	275 lb/ton				41,000
2. Sweating furnaces	64,000 tons, auto radiators	15	0.95	0.20	0.19	400
3. Blast furnaces	287,000 tons, scrap and residue	50 lb/ton scrap	0.90	0.75	0.68	2,300
B. Smelting and Refining	1,170,000 tons scrap					
1. In secondary smelters, etc.						
(a) charge		30 lb/ton charge				
(b) refine		39				
(c) pour		0.6				
		70	0.95	0.60	0.57	17,000
		Total from Secondary Copper				60,700
II. Aluminum						
A. Sweating Furnaces	500,000 tons of scrap	32 lb/ton scrap	0.95	0.20	0.19	6,000
B. Refining Furnaces	1,015,000 tons scrap					
1. Reverberatory		4 lb/ton scrap	0.95	0.60	0.57	900
2. Pot (crucible)		2 lb/ton scrap	--	--	--	--
3. Induction		--	--	--	--	--
C. Fluxing	136,000 tons Cl used	1,000 lb/ton Cl used	--	--	0.25	51,000
D. Dross Processing						
1. Hot process						
2. Milling process						
		Total from Secondary Aluminum				57,900
III. Lead Furnaces						
A. Pot	53,000 tons scrap	0.8 lb/ton scrap	0.95	0.95	0.90	< 100
B. Blast Furnace	119,000 tons scrap	190 " "	0.95	0.95	0.90	1,000
C. Reverberatory		130 " "	--	--	--	--
D. Rotary Reverberatory		70 " "	--	--	--	--
Average, reverberatory	554,000 tons scrap	100 lb/ton scrap	0.95	0.95	0.90	3,000
		Total from Secondary Lead				4,000
IV. Zinc						
A. Sweating						
1. Metallic scrap	52,000 tons scrap	12 lb/ton charge	0.95	0.20	0.19	300
2. Residual scrap	210,000 tons scrap	30	0.95	0.20	0.19	2,600
B. Distillation Furnace	233,000 tons Zn recovered					
1. Distillation retort		47 lb/ton Zn				
2. Muffle		45 lb/ton Zn				
Average, distillation furnaces		45 lb/ton Zn	0.95	0.60	0.57	2,200
		Total from Secondary Zinc				5,100
		Total from Secondary Nonferrous Metals				127,700

4.15.1.1 Burning of Insulation from Wire: The following emission factors are listed for the burning of insulation from wire.[1] The percent combustible is the percent of total weight, copper wire plus insulation.

multi-chamber incinerators
   356 lb. particulate/ton charge - 35% combustible
   190 - 19%
multi-chamber incinerators with secondary burner
   35 lb. particulate/ton of charge - 16% combustible
   21 - 35%
furnace with secondary combustion
   20 lb. particulate/ton of charge - 23% combustible

Wire is burned in the open as well as in incinerators. No information was obtained on the amounts of wire burned by these three means: (1) in the open, (2) incinerators without secondary burners, and (3) incinerators with secondary burners. A small amount may be cleaned by hand, but information from personnel in the industry indicates that this amount would be insignificant. We assume as an average condition that the total amount of wire is burned in incinerators without secondary burners and that the emission factor is 275 lb. of particulate per ton of wire burned.

The amount of scrap wire from which the insulation has been burned off was estimated by an industrial source[16] to be about 20% of the total amount of scrap recovered. The total scrap listed in Reference 2 is 1,662,000 tons for 1968; 20% would be 330,000 tons. The amount of particulate emissions from burning insulation off of copper wire is calculated as follows:

$$E = 300{,}000 \text{ tons wire} \times \frac{275 \text{ lb. partic.}}{\text{ton wire}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 41{,}200 \text{ tons}$$

of particulate matter discharged to the atmosphere in 1968 from burning insulation off of copper wire

4.15.1.2 Sweating Furnaces: The particulate pollution from sweating furnaces is considered to be mainly from the sweating of automobile radiators. Reference 2 lists 64,000 tons of automobile radiators consumed as scrap in 1968. Reference 1 lists data for aluminum and zinc sweating furnaces which give emission factors of 24 and 13 lb. of particulate per ton of material sweated, respectively. The material sweated in each furnace was castings. From these data, we have assumed an emission factor of 15 lb. per ton of material sweated. Estimate of the emissions from sweating of automobile radiators is as follows.

$$E = 64{,}000 \times \frac{15}{2{,}000} = 482 \text{ tons of particulate generated}$$

Dust collection from sweat furnaces is estimated to be 20% of that generated.[4] Particulate discharged to the atmosphere in 1968 is thus estimated as 400 tons.

4.15.1.3 Blast Furnaces: Factors of 20.1 and 16.8 lb. per ton of material charged are reported[5] as the emission rates at a point following a preliminary collector on the furnace. The type of collector is not stated; but if we assume that it was a settling chamber, the collection efficiency can be assumed to be about 35%; the emission factors for the furnace would be 59 and 48 lb. per ton of material charged to the furnace. From these data we assume an emission factor of 50 lb. per ton of charge. The charge to blast furnaces is "low-grade materials such as slag and skimmings."[6] Tonnage charged is taken from Reference 2 as "low-grade scrap and residues"--287,000 tons in 1968. The particulate emissions from blast furnaces melting scrap copper are estimated as follows.

P = 287,000 tons charged, low-grade scrap and residue
e_f = 50 lb. per ton of charge
C_c = 90%, average collection efficiency of dust collectors installed on blast furnaces melting scrap copper
C_t = 75%, percent of furnace capacity on which dust collectors are installed

$$E = \frac{(287{,}000)(50)(1-0.90 \times 0.75)}{2{,}000} = 2{,}300$$

tons of dust discharged to the atmosphere in 1968 from blast furnaces melting scrap copper

4.15.1.4 Smelting and Refining: Data for emissions from smelting and refining of scrap copper are listed in Table 4.15-2.[7] Data have been obtained for the various cycles of the heat. No data are presented for crucible and electric furnaces.

TABLE 4.15-2

EMISSION FACTORS FOR SMELTING AND REFINING FURNACES RECOVERING SCRAP COPPER AND COPPER ALLOYS
(Lb. particulate per ton of material charged)

Furnace Cycle

Charge	Refine	Pour
12	18	0.7
25	28	0.8
55	98	0.4

Furnace Type

Reverberatory	Rotary
54	30
157	147

These few data show no significant difference between reverberatory and rotary furnaces. Of the three cycles in a heat, the "Pour" cycle is significantly lower in emission rate than the other two cycles. Reference 4 states that the "industry average-emission factor" is 60 to 80 lb. of particulate per ton of ingot produced "for a reverberatory brass-ingot furnace." This average factor is on an end-product basis; for a raw-material basis, the value would be somewhat higher. However, because the raw material in this instance contains a high percent of the end product, the values for each basis are considered equal. An emission factor of 70 lb/ton of scrap was assumed.

Total copper scrap consumed in 1968 was 1,660,000 tons. Of this total, 513,000 tons was consumed by primary smelters and is not included in the total used to calculate the emissions from secondary production of copper. The following tabulation gives the consumption of copper scrap by the principal users of scrap.[8]

Brass mills	595,000 tons
Foundries, chemical plants, miscellaneous users	103,000
Secondary smelters	450,000
Total	1,148,000

The scrap consumed by secondary recovery is taken as 1,150,000 tons. The amount of particulate emissions from smelting and refining copper scrap is estimated as follows.

P = 1,150,000 tons of scrap charged to secondary smelting and refining furnaces

e_f = 70 lb. particulate per ton of scrap charged

C_c = 95%, average operating efficiency of dust collectors installed on furnaces smelting copper scrap

C_t = 60%, percent of capacity on which dust collectors are installed

$$E = \frac{(1{,}150{,}000)(70)(1-0.95 \times 0.60)}{2{,}000} = 17{,}300 \text{ tons of particulate}$$

discharged to the atmosphere in 1968 from furnaces smelting and refining scrap copper

The total emissions for secondary copper production are thus:

Materials preparation	43,000 tons
Smelting and refining	17,300
Total	60,300

4 OF 6

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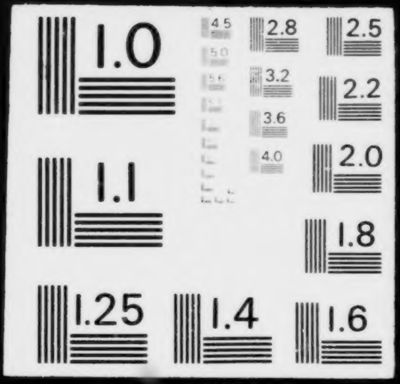

4.15.2 Aluminum

Particulate emissions from the recovery of scrap aluminum come from sweating of scrap metal, melting and refining, and fluxing with chlorine. When dirty scrap is charged to melting furnaces, the emissions will be similar to those from a sweating furnace. Chlorine is used to reduce magnesium content of a charge. The magnesium chloride which forms collects mostly in the dross; but aluminum chloride, which also forms, is vented as a gas which condenses in the stack.[9] The effluent also contains hydrogen chloride and chlorine.

The emission factors for the various processes in recovery of scrap aluminum are taken from Reference 10.

Sweating furnace	32 lb/ton of scrap charged
Reverberatory furnace	4 lb/ton of charge
Crucible furnace	2 lb/ton of charge
Chlorination	1,000 lb/ton of chlorine used

Sweating furnaces are used to melt all kinds of aluminum scrap. Of the total scrap reclaimed, the percent that goes to sweating furnaces is not readily determinable. Some scrap is charged to reverberatory furnaces without being put through a sweating process. Fifty percent of the total scrap consumed is assumed to be processed in sweat furnaces.

Emissions from aluminum sweating furnaces are calculated as follows.

P = 50% of 1,015,000 tons of scrap consumed[11]

e_f = 32 lb/ton of scrap charged

Information on control of pollution from recovery of scrap aluminum is lacking. We have assumed that the control of sweating furnaces for recovery of scrap aluminum is equivalent to the control of pollution in the recovery of scrap copper.

$$E = \frac{(500,000)(32)(1-0.95 \times 0.20)}{2,000} = 6,500 \text{ tons of particulate}$$

discharged to the atmosphere in 1968 from sweating furnaces producing aluminum pig

To estimate the emissions from refining furnaces, we use the factor for reverberatory furnaces. Crucible furnaces and induction furnaces are comparatively small,[1] and we assume that their particulate emissions are negligible. As for sweating furnaces, we assume that the control of pollution from melting furnaces for recovery of scrap aluminum is equivalent to the control of melting furnaces for the recovery of scrap copper. This calculation does not include emissions for chlorine fluxing.

P = 1,015,000 tons of scrap consumed
e_f = 4 lb. per ton of scrap charged
C_c = 95%, average operating efficiencies of dust collectors
C_t = 60%, percent of production capacity on which dust collectors are installed

$$E = \frac{(1,015,000)(4)(1-0.95 \times 0.60)}{2,000} = 870 \text{ tons of particulate}$$

discharged to the atmosphere from refining furnaces (not including chloride emissions)

For estimating emissions from fluxing with chlorine, the principle of material balance is used. The emission factor listed above is based on the amount of chlorine used, but data on chlorine consumption in the industry is not readily obtainable. The ratio of chlorine used is "very roughly" 4 lb. of chlorine per pound of magnesium removed.[7] Assuming that the amount of magnesium in existence as alloy with aluminum is more or less constant in any one year, the amount of new magnesium used in aluminum alloying can be taken as an approximation of the amount of magnesium that was removed in secondary refining. In 1968, 34,000 tons of magnesium were used to make aluminum alloys.[12] Since collection of the chloride particulate from fluxing has been a difficult problem, we assume that at least 75% of the chloride particulate generated escapes to the atmosphere.[7] The particulate emissions from chloride fluxing are estimated as follows.

$$E = \begin{matrix}34,000 \text{ tons of Mg}\\ \text{used in Al alloys}\end{matrix} \times \frac{4 \text{ tons Cl used}}{\text{ton Mg removed}} \times \frac{0.5 \text{ ton partic. produced}}{\text{ton Cl used}}$$

$$\times \frac{0.75 \text{ ton partic. to atm.}}{\text{ton partic. produced}} = 51,000 \text{ tons of particulate dis-}$$

charged to the atmosphere from chlorine fluxing in the recovery of scrap aluminum in 1968

4.15.3 Lead

Estimate of particulate emissions from recovery of scrap lead is made on the basis of information in Reference 6 and the Minerals Yearbook. Reference 13 lists three types of furnaces which are used for recovery of scrap lead: (1) pot furnaces, (2) blast furnaces, and (3) reverberatory furnaces. Pot furnaces process soft-lead scrap which is of fairly high purity. Blast furnaces process drosses, slags and hard-lead scrap. Hard lead has approximately 8% antimony. Reverberatory furnaces process drosses, battery plates, type metal, cable lead, solder, etc.--designated semi-soft lead.

Emissions from each type of furnace are calculated as follows. Production figures are from the Minerals Yearbook.[14]

1. Pot Furnaces

Emission factor: 0.8 lb. of particulate per ton of scrap charged[13]

Scrap consumed: 53,000 tons of soft lead

$E = \frac{(53{,}000)(0.8)(1-0.95 \times 0.95)}{2{,}000} = 2$ tons of particulate discharged to the atmosphere from pot furnaces

2. Blast Furnaces

Emission factor: 190 lb. of particulate per ton of scrap charged[13]

Scrap consumed:

Hard lead	15,000 tons
Drosses & residues	104,000
	119,000

$E = \frac{(119{,}000)(190)(1-0.95 \times 0.95)}{2{,}000} = 1{,}130$ tons of particulate discharged to the atmosphere from blast furnaces recovering scrap lead

3. Reverberatory Furnaces

Emission factor: The emission factor for reverberatory furnaces is taken as the average of the factor for rotary reverberatory furnaces, 70 lb. per ton, and the factor listed for reverberatory furnaces, 130 lb. per ton. The average is 100 lb. per ton of scrap charged.

Scrap consumed: Scrap consumed in reverberatory furnaces is taken as the difference between the total scrap consumed in the secondary recovery of lead, 726,000 tons, and that ascribed to the other types of furnace, 172,000 tons.

Total scrap consumed	726,000 tons
Scrap consumed in pot and blast furnaces	172,000
Scrap consumed in reverberatory furnaces	554,000

$$E = \frac{(554{,}000)(100)(1-0.95 \times 0.95)}{2{,}000} = 2{,}750$$ tons of particulate discharged to the atmosphere from reverberatory furnaces recovering scrap lead

4.15.4 Zinc

Air pollution from the recovery of scrap zinc comes from sweating furnaces and distillation of the sweated metal. Data on emissions from sweating furnaces indicate that the amount of emissions is as much a function of the type of scrap charged to the furnace as of the type of furnace. The following emission factors have been determined.[8]

Metallic scrap	
kettle furnace-sweat	11 lb/ton of material sweated
reverberatory-sweat	13
Residual scrap	
kettle furnace-sweat	24
reverberatory-sweat	40

We use an emission factor of 12 lb. per ton of material sweated for metallic scrap and a factor of 30 lb. per ton of material sweated for residual scrap.

The amount of metallic scrap reclaimed in 1968 is obtained from the Minerals Yearbook.[2]

New clippings	776 tons
Old zinc	5,112
Engravers' plates	3,610
Die castings	41,420
Rod and die scrap	1,192
	52,110

The amount of residual scrap reclaimed in 1968 is taken as the difference between the total scrap reclaimed and the scrap listed above as metallic scrap. Included in residual scrap are die-cast skimmings, galvanizers' dross, flue dust and chemical residues.

Total scrap reclaimed	262,756 tons
Listed above as metallic scrap	52,110
Residual scrap	210,646

The amount of particulate emissions from sweating metallic scrap is estimated as follows.

P = 52,000 tons of metallic scrap
e_f = 30 lb. of particulate per ton of scrap

Since information on the control of particulate pollution for sweating zinc scrap is lacking, we assume that the control is equivalent to the control of pollution from sweating furnaces used to recover scrap copper.

C_c = 95%, average operating efficiency of dust collectors
C_t = 20%, percent of production capacity on which dust collectors are installed

$$E = \frac{(52{,}000)(12)(1-0.95 \times 0.20)}{2{,}000} = 253 \text{ tons per year from sweating metallic residues}$$

The amount of particulate emissions from sweating residual scrap is estimated as follows:

P = 210,000 tons of residual scrap
e_f = 30 lb. of particulate per ton of scrap
C_c = 95%, average operating efficiency of dust collectors
C_t = 20%, percent of production capacity on which dust collectors are installed

$$E = \frac{(210{,}000)(30)(1-0.95 \times 0.20)}{2{,}000} = 2{,}560 \text{ tons in 1968 from sweating residual scrap}$$

Distillation of the molten metal from sweating furnaces is carried out in three types of retorts: (1) Belgian retorts, (2) distillation retort furnaces, and (3) muffle furnaces. Belgian retorts are the oldest and are being replaced by the newer types. Muffle furnaces can be operated continuously. Emission factors are listed in Reference 13 as 47 lb. of particulate per ton of zinc recovered for "Retort Reduction Furnace" and 45 lb. per ton for muffle furnaces. We use 45 lb. per ton to estimate the emission from distillation in the recovery of scrap zinc.

P = 233,000 tons zinc recovered
e_f = 45 lb. particulate per ton of zinc recovered
C_c and C_t: These values are assumed to be the same as for refining furnaces used to recover scrap copper
C_c = 95%, average operating efficiency of dust collectors
C_t = 60%, percent of production capacity on which dust collectors are installed

$$E = \frac{(233{,}000)(45)(1-0.95 \times 0.60)}{2{,}000} = 2{,}250 \text{ tons of particulate in 1968 from distillation of reclaimed zinc.}$$

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SECONDARY NONFERROUS METALS

1. Air Pollution Engineering Manual, Public Health Service Publication No. 999-AP-40, 1967, p. 495 ff.

2. 1968 Minerals Yearbook, Vol. I-II; Bureau of Mines, U. S. Department of the Interior, p. 478, Table 21.

3. Kirk-Othmer Encyclopedia of Chemical Technology, second edition; John Wiley and Sons, New York, 1965, Vol. 6, p. 138.

4. "Air Pollution Aspects of the Brass and Bronze Smelting and Refining Industry," National Air Pollution Control Administration Publication No. AP-58, November, 1969, p. 43.

5. Ibid., p. 42.

6. Ibid., p. 22.

7. Ibid., pp. 38, 39, 41.

8. 1968 Minerals Yearbook, op. cit., p. 479, Table 22.

9. Tomany, J. P., "A System for Control of Aluminum Chloride Fumes," Journal of the Air Pollution Control Association, June 1969, p. 421.

10. Duprey, R. L., "Compilation of Air Pollutant Emission Factors," Public Health Service Publication No. 999-AP-42, 1968, p. 29.

11. 1968 Minerals Yearbook, op. cit., p. 153, Table 4.

12. Ibid., p. 671, Table 3.

13. "Air Pollutant Emission Factors," report of the Division of Air Quality and Emissions Data, National Air Pollution Control Administration, April 1970, prepared by TRW Systems Group of TRW, Inc., Contract No. CPA 22-69-119, pp. 6-21 ff.

14. 1968 Minerals Yearbook, op. cit., p. 645, Table 8.

15. Information from report in preparation, Dr. William Herring, Division of Proc. Cont. Engineering, National Air Pollution Control Administration, Durham, North Carolina, May 13, 1970.

16. Private communication, industrial source.

4.16 Coal Preparation Plants

The major source of particulate emissions in coal preparation plants is the thermal dryer. Transfer points, loading and unloading points, and crushing, grinding, and screening operations are secondary sources. Burning coal-refuse piles are also significant pollution sources.

Thermal drying usually involves the combustion of coal and the passage of combustion gases through a bed of wet coal. Thermal dryers are of various types: (1) rotary, (2) continuous carrier, (3) vertical tray and cascade, (4) multilouvre, (5) suspension or flash, and (6) fluidized bed. Because of higher capacity potential, the utilization of fluidized bed techniques for thermal drying has expanded in recent years.[1,2]

The size consistency of the coal being dried and the velocity of the gases through the bed are major factors in determining the air pollution potential of the plant. Emissions include products of combustion and entrained coal fines.

The calculation of emissions from thermal dryers based on the use of an emission factor is not accurate since the emissions from each type of dryer vary over a wide range depending on operating methods. The flash dryer carries all of the product into a product separation cyclone, while the fluid bed type may carry over from 5% to 50% of the product into the cyclone collection system. For these reasons, the emissions are best calculated on the basis of average outlet grain loadings from control equipment, as was done in a recent internal NAPCA study dated February 27, 1970.[3]

The NAPCA study included a survey of thermal dryers operated at 8 of the largest coal companies. The survey covered about 60% of the total coal dried yearly in the U.S. It determined a total air flow from these dryers of 1.16×10^{12} SCF/yr.[3]

This survey also indicated that 50% of the dryers were equipped with cyclones, while the remaining 50% were equipped with cyclones plus some type of wet scrubber. Total emissions were then calculated to be in the order of 300,000 tons/yr assuming an outlet grain loading of 4.0 gr/SCF from cyclones, 0.15 gr/SCF from low energy scrubbers, and 0.04 gr/SCF from high-energy scrubbers.

The assumed grain loadings have been found to correspond with data in the literature and data from the West Virginia Air Pollution Control Commission. However, the fact that 50% of the dryers are equipped with only cyclones seemed low in view of a 1967 West Virginia Air Pollution Control Commission survey which indicated that less than 15% of the dryers in that state had cyclones only.[4]

Further analysis of the NAPCA survey showed that 50% of the dryers did have cyclones only, but these represented only 13.8% of the total air flow. On this basis, the emissions are calculated in the following manner:

$$E = (1.16 \times 10^{12}\ \frac{\text{SCF}}{\text{yr}})(13.8\%)(4\ \frac{\text{gr}}{\text{SCF}})(\frac{1\ \text{ton}}{14 \times 10^{6}\ \text{grains}}) = 45{,}700\ \text{tons/yr}$$

$$E = (1.16 \times 10^{12}\ \frac{\text{SCF}}{\text{yr}})(86.2\%)(0.15\ \frac{\text{gr}}{\text{SCF}})(\frac{1\ \text{ton}}{14 \times 10^{6}\ \text{grains}}) = 10{,}700\ \text{tons/yr}$$

$$\text{Total} \quad \overline{56{,}400\ \text{tons/yr}}$$

Then, if this represents about 60% of the coal dried, the total annual particulate emissions from thermal dryers are 94,000 tons/yr.

A second method of calculating emissions, for comparison purposes, can be done on the basis of emission factors for the dryers. Data in Reference 5 shows that the emission factor for the outlet of the dryer cyclone is 12 lb/ton for flash dryers and 13 lb/ton for fluid bed dryers. The emission factor for the other types of dryers are probably somewhat lower since their mode of operation should not carry out as much dust to the cyclone. This includes the rotary, continuous carrier, cascade, and multilouvre dryers.[6] However, it might be assumed that the average overall emission factor is 12 lb/ton although this may be somewhat high. The calculation of the emissions also involves the question of what percent of the coal is dried in units that are equipped with wet scrubbers. The two calculations given below show the quantities emitted on the basis of two different assumptions. The efficiency of the wet scrubbers has been estimated at 95% for both cases.

a. It is assumed that 50% of the coal is dried in units equipped with wet scrubbers. This is similar to the NAPCA study which assumed that 50% of the total air flow for all dryers is cleaned in wet scrubbers. The NAPCA survey actually showed that 50% of the number of dryers were equipped with wet scrubbers and it was presumed that this also represents 50% of the total air flow. The emissions for this assumption are calculated as:

$$E = (\frac{73{,}000{,}000\ \text{tons}}{\text{yr}})(\frac{12\ \text{lb}}{\text{ton}})(\frac{2{,}000\ \text{lb}}{\text{ton}})(1-0.50 \times 0.95) = 230{,}000\ \text{tons/yr}$$

b. It is assumed that 85% of the coal is dried in units equipped with wet scrubbers. This assumption is based on our analysis of the data in the NAPCA survey and is supported by information from the West Virginia Air Pollution Control Commission. The emissions for this assumption are calculated as:

$$E = (\frac{73{,}000{,}000\ \text{tons}}{\text{yr}})(\frac{12\ \text{lb}}{\text{ton}})(\frac{2{,}000\ \text{lb}}{\text{ton}})(1-0.85 \times 0.95) = 83{,}000\ \text{tons/yr}$$

These results support the previously discussed emission calculations but do not resolve the question of the extent to which thermal dryers are equipped with wet scrubbers. Based on the present information and calculations described in this section, it is felt that the emission quantity of 94,000 tons/yr is the more accurate figure.

Insufficient data were available to calculate particulate emission rates from the secondary sources. Also, data could not be found on particulate emissions from burning coal-refuse banks. Reference 5 reports an emission level of 400,000 tons/yr of particulate from coal refuse. This figure was calculated assuming that the emission factor for refuse piles corresponds to that for open burning. This is a questionable assumption, and the number of 400,000 tons per year is considered a gross estimate.

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1. Schrecengost, H. A., and Maurice S. Childers, "Fire and Explosion Hazards in Fluidized-Bed Thermal Coal Dryers," Bureau of Mines Report, 1965.

2. Brown, H. R., et al., "Fire and Explosion Hazards in Thermal Coal-Drying Plants," Bureau of Mines Report of Investigations, 5198.

3. Internal Study on Coal Dryer Emissions, Div. of Proc. Cont. Engineering, National Air Pollution Control Administration.

4. Private communication from Mr. David Ellis, West Virginia APC Commission, Charleston, West Virginia.

5. Research Triangle Institute, Final Report, "Comprehensive Economic Cost Study of Air Pollution Control Costs for Selected Industries and Selected Regions," NAPCA Contract No. CPA 22-69-79, February 1970, p. T-4.

6. Coal Preparation, Third Ed., American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., New York, 1968, p. 13-8.

7. National Emission Standard Study, Senate Document No. 91-63 (March 1970).

4.17 Carbon Black

Carbon black is ultrafine soot manufactured by the burning of hydrocarbons in a limited supply of air. This finely divided material (10 to 400 mμ in diameter) is of industrial importance as a reinforcing agent for rubber and as a colorant for printing ink, paint, paper, and plastics.

Three basic processes currently exist in the United States for producing this compound. They are: the furnace process accounting for about 83% of production; the older channel process which accounts for about 6% of production; and the thermal process. Atmospheric pollutants from the thermal process are negligible since the exit gases which are rich in hydrogen are used as fuel in the process. In contrast, the pollutants emitted from the channel process are excessive and characterized by copious amounts of highly visible black smoke. There are only three channel plants still in operation, and they are all located in western Texas. Emissions from the furnace process consist of carbon dioxide, nitrogen, carbon monoxide, hydrogen, hydrocarbons, particulate matter, and some sulfur compounds.1/ A summary of estimated emissions is given in Table 4.17-1.

The most important factor affecting emissions is the basic manufacturing process and its inherent inefficiency. Thus, emissions from the channel black process are excessive, while those from the thermal process are negligible. Particulate emissions from the furnace process are affected by the type of collection equipment used. Gaseous emissions are largely determined by the overall yield, type of fuel (that is, liquid or gas), the reaction time and temperature, the ratio of gas to oil in the feed, and the amount of combustion air.

Additional emissions may occur from the conveying, grinding, screening, drying, and packaging operations at a carbon black plant. Poorly designed or maintained equipment can result in leaks and spills. Spillage of the fluffy black before pelleting is the source of pollution.

When pellets cease to form in the dry pelleting process the drum has to be emptied and reloaded with fresh loose black, be reseeded, and pelleting resumed. The emptying of the drum will naturally result in black spillage.

Maintenance operations will often result in carbon black spillage. The cleaning of clogged screens, located either at the top of the storage tank into which the finished black is screened or at the pelleting section where oversized pellets are screened out, causes black to be discharged in the atmosphere. Whenever a production line is plugged the remedial measures are either to pound the line or use a vibrator. If this proves ineffective

TABLE 4.17-1

PARTICULATE EMISSIONS FROM THE MANUFACTURE OF CARBON BLACK

Source	Quantity of Material	Emission Factor	Application of Control C_c	Efficiency of Control C_t	Net Control $C_c \cdot C_t$	Emissions (tons/yr)
I. Channel process	71,500 tons, carbon black	2,300 lb/ton product	0.0	0.0	0.0	82,000
II. Furnace process						
A. Gas	156,000 tons, carbon black	60 lb/ton product*	---	---	---	5,000
B. Oil	1,180,000 tons, carbon black	10 lb/ton product*	---	---	---	6,000
					Total	93,000

---

* See Table 4.17-2.

high-pressure air is used to dislodge the black. Carbon black is generally emitted to the atmosphere in this operation.

Carbon black is so finely divided that whenever a leak develops in plant equipment, such as in the conveyor system, or in the bins, or at the bagging equipment, black will seep out into the atmosphere.

Emission factors for carbon black manufacture were taken from Reference 1, and are summarized in Table 4.17-2. Factors for the channel black process are questionable due to a complete absence of emission data.

Production of carbon black was 1.4 million tons in 1968. The furnace process accounted for 1.33 million tons and the channel process 71,475 tons.[2]

TABLE 4.17-2[1]

EMISSIONS FROM CARBON BLACK MANUFACTURING PROCESSES, LB/TON OF PRODUCT

Process	Particulate
Channel[a]	2,300 (2,000 to 5,000)
Thermal	neg.
Furnace	
Gas	220[b] 60[c]
Oil	10[d]

---

[a] Based on yield of 1.5 lb. of carbon black per 1,000 ft.^{3} of gas feed.

[b] 90% overall collection efficiency, that is, no collection after cyclone.

[c] 97% overall collection efficiency, that is, cyclones followed by scrubber.

[d] 99.5% overall collection efficiency, that is, fabric filter system.

Note: Emission ranges are due to variations in operating conditions and not any specific factors.

The emission calculations are as follows:

4.17.1 Channel Process:

$$E = \frac{(7.15 \times 10^4 \text{ tons/yr})(2.3 \times 10^3 \text{ lb/ton})}{2 \times 10^3} = 82{,}225 \text{ tons}$$

4.17.2 Furnace Process:

4.17.2.1 Gas Process: Production of carbon black by the gas furnace process amounted to 156,000 tons in 1968.[2] The controlled emission factor was assumed to be 60 lb/ton of product.

$$E = \frac{(1.56 \times 10^5 \text{ tons/yr})(60 \text{ lb/ton})}{2 \times 10^3} = 4{,}700 \text{ tons}$$

4.17.2.2 Oil Process: Production of carbon black by the oil furnace process amounts to 1.18 million tons in 1968.[2]

$$E = \frac{(1.18 \times 10^6 \text{ tons/yr})(10 \text{ lb/ton})}{2 \times 10^3} = 5{,}900 \text{ tons}$$

4.17.2.3 Materials Handling: Due to the variability of these emissions, no emission estimate is possible.

4.17.2.4 Summary of Emissions: The current particulate emissions from carbon black manufacture are:

Channel Process	82,225 tons
Gas Furnace Process	4,700 tons
Oil Furnace Process	5,900 tons
	92,825 tons

REFERENCES

CARBON BLACK

1. "Air Pollutant Emission Factors," report of the Division of Air Quality and Emissions Data, National Air Pollution Control Administration, April 1970, prepared by TRW Systems Group of TRW, Inc., Contract No. 22-69-119, p. 4-20.

2. Minerals Yearbook Vol. I-II, Bureau of Mines, 1968, p. 235, Table No. 1.

4.18 Petroleum Refining

The petroleum industry can logically be divided into three major divisions; production, refining, and marketing. Production includes the operations involved in locating and drilling oil fields, removing oil from the ground, pretreatment at the well site, and transporting the crude to the refinery. Refining is limited to operations necessary to convert the crude into salable products. Marketing involves the distribution and sale of finished petroleum products. Only the refining operations will be considered in this discussion.

The emission of particulate matter from refineries may originate from catalyst regeneration, decoking operations, airblown asphalt stills, sludge burner, boilers, process heaters and incinerators.1/ Flare systems may also result in particulate emissions due to formation of carbon particles but this is a result of the combustion process at the flare. Emissions from boilers and process heaters are included in the stationary combustion source category. The catalyst regenerator is the remaining major particulate emission source.

In the production of high-octane gasoline, oil and powdered catalyst are mixed in a reactor. Spent catalyst, containing residual carbon (or coke) from the catalytic cracking process taking place in a reactor, is mixed with combustion air and fed to the regenerator in order to reactivate the catalyst by burning off the coke or residual carbon formed on the catalyst. After regeneration, the hot incinerated catalyst is mixed with crude oil and is transported back to the reactor and the cycle repeated.

The gaseous products of combustion from the top of the regenerator are exhausted through a series of mechanical collectors which return their catch directly to the fluid bed. The finer fractions of the catalyst escape along with the discharged gas. The exhaust gases may be further cleaned with additional cyclones or an electrostatic precipitator.

Emission rates from catalyst regenerator units could not be calculated by the methods of emission factors because of the high extent of control. Available data indicate that one 6,000 BPSD (barrel per stream day) FCC unit emits 0.135 ton of dust/day based on 0.016% dust in the air stream out of the final separator.1/ The total capacity of FCC units is 3,609,000 BPSD.2/ By direct ratio:

$$\text{Emission from FCC} = \left(\frac{3,609,000}{6,000}\right)(0.135\ \text{ton/day}) = 81\ \text{tons/day}$$

$$= 24,000\ \text{tons/yr}$$

The emissions may be calculated by another method. Information from Reference 3 indicates catalyst "losses" range from 0.05-0.1 lb/bbl fresh feed. Using the average of 0.075 lb/bbl, the emissions would be:

$$\left(\frac{0.075\ \text{lb}}{\text{bbl}}\right)\left(\frac{3.609 \times 10^6\ \text{bbl}}{\text{day}}\right)\left(\frac{330\ \text{day}}{\text{yr}}\right)\left(\frac{1\ \text{ton}}{2{,}000\ \text{lb}}\right) = 44{,}700\ \text{ton/yr}$$

The latter figure of 44,700 tons/year is probably more representative because the former figure is based on data from only one plant.

Emissions from decokers and asphalt stills were not determined because of lack of data on emissions from these sources. Discussions with refinery engineers indicated these sources were probably small compared to regenerators.

REFERENCES

PETROLEUM REFINING

1. Private Communication, Industrial Source.
2. "Production Statistics," Oil and Gas Journal, March 24, 1969.
3. Hydrocarbon Processing, 1968 Refining Process Handbook. Houston, Texas, Gulf Publishing Co., September, 1968, pg. 147.

4.19 Mineral Acids

Particulate pollution from the manufacture of mineral acids is significant only for sulfuric acid and phosphoric acid. Air pollutants from the manufacture of hydrochloric acid and nitric acid are in a gaseous state in the discharge stacks except for a hydrocarbon mist discharge with hydrogen chloride in the manufacture of hydrochloric acid. The quantity of hydrocarbon mist is considered to be insignificant with regard to tonnage.

Particulate pollutants from the manufacture of both sulfuric acid and phosphoric acid are acid mists from the absorption equipment. Dust from handling and stockpiling solid sulfur is a secondary source. The most important source of sulfuric acid mists appears to be airblown concentrators used in the recovery of spent acid in such processes as the manufacture of nitroglycerine from which the acid emerges chemically unchanged. Although sulfuric acid is a comparatively inexpensive material, its recovery in these instances is economical.

A summary of emission factors and estimated quantities of emissions is given in Table 4.19-1. Values of C_c and C_t used in the calculations are discussed in Chapter 5, pp. 237-238.

4.19.1 Sulfuric Acid

There are two processes in current use for manufacturing sulfuric acid: (1) the chamber process, and (2) the contact process. In both processes, acid is produced by absorption of sulfur trioxide in water. In the chamber process, oxides of nitrogen are used to oxidize sulfur dioxide to sulfur trioxide; in the contact process, the oxidation of sulfur dioxide is effected by catalytic action.

The emission factors for absorption towers in sulfuric acid manufacture are obtained from Reference 1. The factors in the reference are listed on a time basis, tons of mist per day; the factors used here, which are based on process weight, have been calculated from the production data given in the reference. The emission rates in Reference 1 for the contact process have been classified by source of the sulfur as follows:

1. Elemental sulfur
2. Metallurgical gas
3. Spent acid
4. Wet gas

Emission rates from elemental sulfur are further classified by (1) state of the sulfur, solid or molten, and (2) degree of refinement, bright or dark. Table 4.19-2 shows the emission factors calculated for these various

TABLE 4.19-1

PARTICULATE EMISSIONS
MINERAL ACIDS

Source	Quantity of Material	Emission Factor	Efficiency of Control C_c	Application of Control C_t	Net Control $C_c \cdot C_t$	Emissions ton/yr
I. Sulfuric Acid						
A. Processing Units	28,000,000 tons of H_2SO_4					
1. Gay-Lussac tower (chamber process)	1,000,000 tons of H_2SO_4	5 lb/ton H_2SO_4	0.0	0.0	0.0	2,000
2. Absorber (contact process)	27,000,000 tons of H_2SO_4	2 lb/ton H_2SO_4	0.95	0.90	0.85	4,000
B. Spent-Acid Concentrators						
1. Air-blown	11,200,000 tons of spent acid	30 lb/ton of spent acid	0.95	0.85	0.80	8,000
2. Vacuum						Neg.
II. Phosphoric Acid - Thermal Process	1,020,000 tons of P_2O_5	134 lb. particulate/ ton of P_2O_5 produced	0.97	1.0	0.97	2,000
				Total from Acids		16,000

TABLE 4.19-2

AVERAGE EMISSION FACTORS FOR SULFURIC ACID PLANTS USING THE CONTACT PROCESS

Plant Type	Raw material	Emission Factor lb. particulate/ton H_2SO_4 Without mist eliminator	With mist eliminator
Sulfur burning, air dilution	molten dark	2.5	0.1
	molten recovered	1.1	
Sulfur burning, no air dilution	molten recovered	0.9	
	solid, bright	1.7	
	solid, dark	1.2	
	molten dark	3.7	3.0
Metallurgical	pyr't spent acid	1.2	
	pyr't	7.4	
	by-product gas	3.2	
Spent acid	spent acid and sulfur	2.3	
	spent acid	2.2	
	spent acid, H_2S sulfur		0.2
Wet gas	H_2S, sulfur		1.2

classifications. The range for the 11 factors tabulated is 0.9-7.4 lb. per ton of H_2SO_4 obtained as end product; ten of the eleven are below 4 lb. per ton. Inspection of Table 4.19-2 suggests that processes using metallurgical gases may have the highest rate of particulate emissions; no difference is evident between states of the sulfur.

The emission factors for the contact process can also be tabulated according to towers utilizing mist eliminators and towers without mist eliminators. The arithmetic average for 21 items in the data for "without mist eliminator" group is 2.2 lb. per ton. The average for nine items in the "with" group is 0.9 lb. per ton. The average for the "without" group is approximately twice that of the "with" group. This is less than the difference within the groups; however, a statistical test (t-test) on the difference between the means for the "with" group is significantly less than the mean for the "without" group. Table 4.19-3 is a tabulation of the statistical calculations. In making inferences from the statistical calculations, it should be noted that a wide dispersion of the data is indicated by the large values of the standard deviations relative to the means.

The average of all 30 items of data given in Reference 1 for contact plants is approximately 2 lb. of particulate discharged from absorption towers per ton of 100% H_2SO_4 obtained as end product. This factor was used to estimate the particulate pollution from contact plants as follows:

$$E = (27{,}000{,}000)\left(\frac{2}{2{,}000}\right)(1-0.95 \times 0.90) = 4{,}000 \text{ tons}$$

For chamber process plants, only two items of data are given in Reference 1. Emission factors of 2.3 lb. per ton for molten dark sulfur as the raw material and 8.6 lb. per ton for solid sulfur as the raw material are calculated. An average of the two factors, 5 lb. of particulate per ton of 100% H_2SO_4 obtained as end product, was used to estimate the quantity of emissions from plants manufacturing sulfuric acid by the chamber process.

$$E = (1{,}000{,}000)\left(\frac{5}{2{,}000}\right) = 2{,}500 \text{ tons}$$

Spent acid concentrators have been acknowledged as an important source of air pollution,2/ but information in the literature concerning the air-pollution aspects of acid concentrators is scarce. There are two types of concentrators: (1) airblown concentrators, and (2) vacuum concentrators. The economics of the two types are such that airblown concentrators are favored where the desired strength of the re-concentrated acid exceeds 80%. Nearly all concentrators are of the airblown type.

TABLE 4.19-3

COMPARISON OF EMISSION FACTORS
PLANTS WITH MIST ELIMINATORS VS. PLANTS WITHOUT MIST ELIMINATORS

Emission Factors	Plants with mist eliminators	Plants without mist eliminators
No. of emissions factors, N	21	9
Arithmetic average of emission factors, $\overline{X}$	0.1 $\frac{\text{lb. mist}}{\text{ton } H_2SO_4}$	2.2 $\frac{\text{lb. mist}}{\text{ton } H_2SO_4}$
Standard deviation, s	1.7	2.1

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{S_1^2 + S_2^2}{N_1 + N_2}}} = 1.74$$

$$\text{degrees of freedom} = \frac{\left(\frac{S_1^2 + S_2^2}{N_1 + N_2}\right)^2}{\left(\frac{S_1^2}{N_1}\right)\frac{1}{N_1 + 1} + \left(\frac{S_2^2}{N_2}\right)\frac{1}{N_2 + 1}} - 2 = 22$$

Hypothesis: The emission factor for plants using mist eliminators is less than the emission factor for plants not using mist eliminators.

Probability$_{0.05}$: $t = 1.72$

Probability$_{0.025}$: $t = 2.07$

Statistical formulas from Walker and Lev, Statistical Inference, Henry Holt and Co., New York, 1953, pp. 157-158.

The following data were used to calculate an emission factor for air-blown spent-acid concentrators.[2]

Volume of gas from concentrators	89,000 cu ft/min
Gas temperature	166°C
Avg. mist concentration	117 mgm/std cu ft
Process weight	700 tons/day of spent acid

$$89{,}000\ \frac{\text{cu ft}}{\text{min}} \times \frac{273}{439} \times \frac{117\ \text{mgm}}{\text{std cu ft}} \times \frac{1\ \text{lb}}{454{,}000\ \text{mgm}} \times 1440\ \frac{\text{min}}{\text{day}}$$

$$\times\ \frac{1\ \text{day}}{700\ \text{tons spent acid}} = \frac{30\ \text{lb mist}}{\text{ton of spend acid}}$$

This acid was being concentrated from 70% to 95%.

There are presently 160 spent-acid concentrators in the United States; 147 of these are in ordnance plants. The average capacity is approximately 200 tons of spent acid per day.[3] The capacity of spent-acid concentrators is thus:

$$160\ \text{units} \times 200\ \frac{\text{tons}}{\text{unit-day}} \times 350\ \frac{\text{days}}{\text{year}} = 11{,}200{,}000\ \text{tons per year}$$

Concentrators in ordnance plants operate, on an annual average, at much less than capacity, possibly only ten percent of the time.[3] If a utilization factor of 0.25 is assumed for the total capacity, the following estimate can be made for the quantity of particulate emissions from spent-acid concentrators.

$$E = 11{,}200{,}000 \times 0.25\ \text{tons acid} \times 30\ \frac{\text{lb particulate}}{\text{ton spent acid}} \times \frac{1\ \text{ton}}{1{,}000}$$

$$\times\ (1 - 0.95 \times 0.85) = 8{,}000\ \text{tons discharged to the atmosphere}$$

4.19.2 Phosphoric Acid

Under this heading is discussed only the thermal process for manufacturing phosphoric acid. The wet process, used extensively in the fertilizer industry, is discussed in Section 4.11, Fertilizers and Phosphate Rock, p. 146.

Manufacture of phosphoric acid by the thermal process involves combustion of phosphorous to form phosphorus pentoxide which is absorbed in water to form phosphoric acid. The source of particulate emissions is the effluent gas stream from the absorption process which contains a mist of phosphoric acid. Because the particulate emission is product, collection equipment is installed.

The emission factor for the thermal process is derived from data in Reference 4. Data from eight plants yields a geometric mean of 134 lb. of mist per ton of P_2O_5 obtained as end product. The range is 36-869 lb. per ton; the arithmetic mean is 212 lb. per ton. Values for seven of the eight plants are at or below 200 lb. per ton. Estimate of the quantity of particulate emissions from the thermal process for manufacture of phosphoric acid is as follows:

$$E = 1{,}020{,}000 \text{ tons } \frac{P_2O_5}{\text{yr}} \times 134 \frac{\text{lb mist}}{\text{ton } P_2O_5} \times (1 - 0.97 \times 1.0)$$

$$\times \frac{1 \text{ ton}}{2{,}000 \text{ lb.}} = 2{,}000 \text{ tons/yr}$$

REFERENCES

MINERAL ACIDS

1. Atmospheric Emissions from Sulfuric Acid Manufacturing Processes, Public Health Service Publication No. 999-AP-13; 1965.

2. Clauss, N. W., "The Reduction of Atmospheric Pollution from Sulfuric Acid Recovery Processes," Air Repair, February 1954, pp. 131-136.

3. Private communication, Chemical Construction Company, New York, July 1970.

4. Atmospheric Emissions from Thermal-Process Phosphoric Acid Manufacture, National Air Pollution Control Administration Publication, No. AP-48, October 1968.

4.20 Secondary Sources

Secondary sources are defined as operations that are ancillary to the main processing units in a plant. The secondary sources in a plant are generally multiple sources in contrast with a major source which, in many industries, can be identified as a single piece of equipment. With regard to particulate pollution, boilers in the electric-utility industry, kilns in the cement industry, furnaces in the iron and steel industry, aggregate dryers in asphalt plants and catalytic cracking units in petroleum refineries are further examples of major sources. These major sources are all equipment in which some kind of processing takes place. It may be noted that all of the equipment mentioned involves heat transfer.

The following outline lists some secondary sources which are common to many plants.

I. Processing equipment
    A. Size reduction
        1. Crushers
        2. Grinders
        3. Mills
    B. Size separation - screens

II. Materials handling
    A. Elevators
        1. Boots
        2. Heads
    B. Conveyor discharge points
        1. Transfer points
        2. Discharge to storage
            a. Bins, silos
            b. Stockpiles
    C. Shipping
        1. Unloading of raw materials
        2. Shipment of product
            a. Bulk loading
            b. Bagging

III. Stockpiles - windblown dust

IV. In-plant traffic on dusty roads

In addition to the sources common to many plants, there are secondary sources which are intrinsic to a particular industry--for example, slakers in lime plants and dissolving tanks in Kraft pulp mills.

Particulate emissions from much of the process equipment listed in the outline have been effectively controlled. Equipment which is enclosed, such as a hammermill or an elevator boot, can be easily vented to a dust-collection system. Conveyor transfer points can be effectively hooded. If the conveyor system contains extensive footage, considerable ducting may be required to serve all the transfer points. Stockpiles are a source of dust which more or less defy design of a dust-collection system. One solution to the dust problem of stockpiles is silos, which can be vented to dust-collection equipment. However, the cost of these may be prohibitive if the amount of material to be stored is large. Stockpiles of coal at a steel mill may be as high as 100 feet and cover an area of 10 acres or more. Dust from in-plant traffic over dirt and gravel roads can be a significant source where truck traffic is frequent. Crushed-stone plants consider this source to be a major one in this industry. The best solution found by crushed-stone plants to keep down road dust is the use of water wagons to spray the roads continuously. Collection of dust from processing equipment and materials handling equipment becomes increasingly economical as the value of the dust increases with the amount of processing it has undergone; and where the end product is a dust, such as flour from a flour mill, the problem of air pollution becomes a minor one because of the economic necessity of dust collection.

The sources of secondary pollution such as elevators which are not enclosed, points in conveyor systems at which materials are transferred from one conveyor to another or discharged to storage, and stockpiles are sources of air pollution which are less conspicuous as well as less profuse than cupolas and boiler stacks. Consequently, although such sources have not escaped notice, development of methods for their control has been of less concern. However, the importance of secondary sources relative to the total pollution load is indicated by some of the estimates made for dust from materials handling. In the iron and steel industry, the amount of dust from materials handling is estimated at approximately one-third of the total particulate emissions for the industry. In the lime industry, approximately half of the total emissions is estimated to come from crushing and screening. These proportions are a function of the effectiveness of pollution control on the major sources. The proportion of pollution from secondary sources in an industry increases as the pollution from the major sources decreases; and in the iron and steel industry there has been notable reduction in the rate, i.e., pounds of emissions per ton of product, of emissions from the furnaces. Although the quantity of particulate emissions from blast furnaces is estimated as 58,000 tons (see Table 4.1-1, p. 50), this quantity would be approximately 4,000,000 tons if pollution control of blast furnaces, 0.99%, were of no greater extent than the "Net Control", 0.32%, assumed for materials handling in the industry; and the 446,000 tons estimated for materials handling would be consequently of less significance. Thus, the installation of pollution control equipment on the major sources results in an increase of the significance of secondary sources relative to the total pollution load.

The estimates of particulate pollution from secondary sources suggest that increased attention should be given to: (1) measurement of quantities of pollution from the various secondary sources; and (2) investigation of methods of control of secondary sources.

5. EXTENT OF CONTROL

The quantity of particulates emitted from industrial sources has been, in most cases, calculated on the basis of an emission factor which relates the production rate to the quantity of particulate produced by the process. The quantity thereby obtained is that which would be emitted if no pollution control equipment were used. Therefore, to determine the quantity of particulate emitted to the atmosphere, it is necessary to know if the source is controlled and at what efficiency.

Table 4.1-1 shows the quantity of particulates emitted by the major industrial sources. To prepare this table, it was necessary to know the percent of the production capacity that has controls (application of control), and the average efficiency of the control equipment weighted on the basis of the associated production capacity (efficiency of control). The product of the application and efficiency is the net control, which can be used along with the production rate and emission factor to calculate the quantity of particulate emitted to the atmosphere. The methods used to obtain the net control for each of the industry's shown in Table 4.1-1 are explained in the following sections. The complete computation of the quantities emitted and an explanation of the values used are contained in Section 4.

The net control was determined by phone survey for some of the industries. The people contacted by phone were very cooperative and provided the requested information after some assurances as to its use and the objective of our program. Other techniques for obtaining net control are discussed where they were used.

5.1 Coal-Fired Boilers

5.1.1 Coal-Fired Electric Utility Boilers

A phone survey of electric utilities was carried out to obtain accurate information as to the application and efficiency of control in this industry. This survey contacted 88 companies representing 190 plants and 673 boilers. So that a large percentage of the coal usage in this industry would be covered by the survey, only those plants burning more than 100,000 tons/yr of coal were contacted.

The information requested from each plant is shown on attached Figure 5.1-1. The efficiency of the control equipment was estimated by the plant operator in most cases although a few were based on actual test data. The results of the survey are shown below. Discussion of these results and additional information are presented on the following pages.

Company__________________ Location__________________
Plant No.__________

Number of Boilers__________

Boiler 1:
Type (Pulverized, stoker, cyclone)__________________

Coal Used (tons/yr)__________________

Control Equipment__________________

Efficiency (measured or estimated)__________________

Average % ash in coal__________________

Boiler 2:
Type__________________

Coal Used__________________

Control Equipment__________________

Efficiency__________________

Average % ash in coal__________________

Boiler 3:
Type__________________

Coal Used__________________

Control Equipment__________________

Efficiency__________________

Average % ash in coal__________________

Figure 5.1-1 - Phone Survey Data Form

Results of Phone Survey:

Type of Boilers	Efficiency of Control	Application of Control	Net Control
1) Pulverized	92.3%	96.9%	89.4%
2) Stoker	80.0%	87.4%	70.0%
3) Cyclone	91.0%	70.6%	64.3%

5.1.1.1 Pulverized Coal Boilers: The phone survey covered plants using 136,145,000 tons/yr of coal or 53% of the total 258,400,000 tons/yr of coal used by all pulverized coal boilers in the electric utility industry.

The application of control of 96.9% is weighted on the basis of the quantity of coal used and is believed to be a very accurate figure for the present situation. It must be pointed out that many of the plant operators stated that they were planning to install new control equipment within the next 1-3 years or they were planning to switch over to oil or gas.

The efficiency of control of 92.3% is also weighted on the basis of the quantity of coal used. In most cases the efficiency estimated by the plant operator was within the efficiency range expected for the particular type of control device. It was calculated that for the coal burned in controlled plants using cyclones or electrostatic precipitators, 24.3% used cyclones or multiclones at a weighted average efficiency of 82.2%, while the remaining 75.7% used electrostatic precipitators or cyclones plus an electrostatic precipitator at a weighted average efficiency of 96.0%. This corresponds to an efficiency of control of 92.6% which does not exactly match the calculated value of 92.3% since a few plants still are equipped only with settling chambers.

The average efficiency of 96% for systems with electrostatic precipitators is supported by the fact that a large percentage of electrostatic precipitator capacity has been installed since 1955 with average design efficiency in excess of 96%.[1] The survey figure of 96% also reflects the fact that about 20% of the coal burned utilizing electrostatic precipitators includes a cyclonic device in series with the electrostatic precipitator.

The average efficiency of 82.2% for the cyclone or multiclone systems is based mostly on estimated efficiencies but is within the range of these devices although it is somewhat on the high side. If the efficiency for these devices was assumed to be 70% rather than 82.2% this would reduce the overall efficiency of control from 92.3% to 89.7%.

5.1.1.2 Stoker-Fired Coal Boilers: The phone survey covered 18 plants using 4,444,000 tons/yr of coal or 45% of the total 9,900,000 ton/yr of coal used by all stoker-fired boilers in the electric utility industry.

The application of control and the efficiency of control, weighted on the basis of the quantity of coal used, were found to be 87.4% and 80.1%, respectively. The application of control for stoker boilers is, of course, less than for the pulverized boilers. Also, only 5.2% of coal burned is controlled in boilers equipped with electrostatic precipitators. The remaining 94.8% are equipped with cyclonic collectors.

5.1.1.3 Cyclone-Fired Coal Boilers: The phone survey covered 21 plants using 14,971,000 tons/yr of coal or 52% of the total 28,700,000 ton/yr of coal used by all cyclone-fired boilers in the electric utility industry.

The application of control and the efficiency of control, weighted on the basis of the quantity of coal used, were found to be 70.6% and 91.0%, respectively. The application of control is therefore less than for either pulverized or stoker-fired boilers. However, the survey revealed that the efficiency of control is high (91.0%).because 81.2% of the coal is burned in cyclone controlled boilers that are equipped with electrostatic precipitators.

5.1.1.4 Ash Content of Coals Used: The phone survey of the electric utilities also included a request for information regarding ash content of coal used. It was found that the average ash content for the coal used, weighted on the basis of quantity of coal burned, was as follows:

Type of Boiler	Average Ash Content
Pulverized	11.9%
Stoker	11.2%
Cyclone	11.8%

The average ash content of 11.9% given above agrees exactly with that calculated based on data from a recent survey by the Federal Power Commission.

5.1.2 Coal-Fired Industrial Boilers

A phone survey of industrial coal-fired boilers, similar to the survey of electric utility boilers, was also carried out. This survey contacted 68 companies, each of which burned more than 10,000 tons/yr of coal. The results of the survey are shown below. Discussion of these results and additional information follows.

Type of Boilers	Efficiency of Control	Application of Control	Net Control
(1) Pulverized	84.7%	95.5%	81.0%
(2) Stoker	84.7%	61.7%	52.3%
(3) Cyclone	82.4%	90.5%	74.7%

5.1.2.1 Pulverized Coal Boilers: The phone survey covered 42 plants using 7,055,000 tons/yr of coal or 35% of the total 20,000,000 tons/yr of coal used by all pulverized coal industrial boilers.

The application of control and efficiency of control, weighted on the basis of the quantity of coal used, were found to be 95.5% and 84.7%, respectively. In most cases the efficiency of control was estimated by the plant operator and was within the efficiency range expected for the particulate control device.

It was found that 31% of the controlled plants, on the basis of quantity of coal consumed, were using electrostatic precipitators while most of the remaining 69% were using multiclones.

5.1.2.2 Stoker-Fired Boilers: The survey covered 59 plants using 6,600,000 tons/yr of coal or 9.4% of the total 70,000,000 tons/yr of coal used by all stoker-fired industrial boilers.

The application of control and the efficiency of control, weighted on the basis of quantity of coal used, were found to be 61.7% and 84.7%, respectively.

It was found that 14.8% of the controlled plants, on the basis of quantity of coal consumed, were using electrostatic precipitators while most of the remaining 85.2% were using multiclones. It is interesting to note that the percentage using electrostatic precipitators on industrial stoker-fired boilers is about three times greater than for stoker-fired boilers in the electric utility industry.

5.1.2.3 Cyclone-Fired Boilers: The survey covered 11 plants using 2,230,000 tons/yr of coal or 22.3% of the total 10,000,000 tons/yr of coal used by all cyclone-fired industrial boilers.

The application of control and efficiency of control, weighted on the basis of quantity of coal used, were found to be 90.5% and 82.4%, respectively.

It was found that 55% of the controlled plants, on the basis of quantity of coal consumed, were using electrostatic precipitators while most of the remaining 45% were using multiclones.

The survey indicates that the application of control (90.5%) in industrial cyclone-fired boilers is greater than that for cyclone-fired boilers in the electric utility industry (70.6%).

5.1.2.4 Ash Content of Coal Used: The phone survey of industrial coal-fired boilers also included a request for information as to the ash content of the coal used. It was found that the average ash content was about the same for each type of boiler. However, this average ash content is lower than the average of 11.9% determined for electric utility boilers.

Type of Boiler	Average Ash Content
Pulverized	10.6%
Stoker	10.2%
Cyclone	10.3%

5.2 Crushed Stone and Sand and Gravel

5.2.1 Crushed Stone

The extent of control for crushed stone is based on discussions of industry practice with members of the National Crushed Stone Association. The 25% application of control is indicative of the fact that the particulate sources in the crushed stone operations are many and varied. Most of the sources are of the "fugitive" type and effective control is difficult. Conventional methods of control, including water spray systems, are used for the crushing and grinding operations, but no data have been located to determine the efficiency of these systems as applied to crushed stone. This efficiency was estimated to average about 80%.

5.2.2 Sand and Gravel

The net control for sand and gravel operations has been assumed to be zero since many of the operations are performed wet, as evidenced by the relatively small emission factor shown in Table 4.1-1.

5.3 Agriculture Operations

5.3.1 Grain Elevators

The extent of control for grain elevators has been determined by discussions with the industry and a supplier of control equipment for that industry. These discussions have pointed out that almost all elevators do use some cyclones but there are many points of emission in each elevator. Very little data have been collected as to the relative quantities emitted from each source within any elevator. Our estimate is 40% for the application of control.

The control equipment used in grain elevators is usually cyclones although some baghouses are being used. Discussions with the control equipment manufacturer and actual testing previously done by MRI indicate that the efficiency of the cyclones can be as high as 90%. However, other testing of cyclones in various services in one elevator showed efficiencies ranging from 45% to 68% with a weighed average of 64.3%. The average of 64.3% appears to be more realistic considering the low specific gravity and small particle size of the emissions. Taking this into account and considering that some baghouses are used, it is estimated that the average efficiency of control is 70%. Therefore, net control is 28%.

5.3.2 Cotton Gins

The extent of control for cotton gins has been determined on the basis of conversations with the Texas Air Control Board and the Cotton Ginning Laboratory of the U. S. Department of Agriculture. These discussions indicate that although most gins do utilize some cyclones, only about 40% of the individual sources have these controls, i.e., application of control = 40%. The efficiency of the cyclones used was estimated to be 80%. Therefore, the net control is 32%.

5.3.3 Feed Mills

5.3.3.1 Alfalfa Mills: The computation of emissions from alfalfa dehydrators uses an emission factor based on the outlet of the first cooling cyclone that is common to all dehydrators. The extent of control, therefore, reflects only the status of equipment used following this first cyclone.

On the basis of projects presently being conducted by MRI it was estimated that plants totaling half the production capacity have additional collection equipment following the first cooling cyclone. This corresponds to an application of control of 50%. Since the additional collection equipment installed is usually a second cooling cyclone of higher efficiency, it was estimated that the efficiency of control is 85%. The resultant net control is 42%.

5.3.3.2 Mills Other Than Alfalfa: Due to lack of information regarding control practices, the efficiency and application of control was assumed to be the same as that for alfalfa mills.

5.4 Iron and Steel

5.4.1 Ore Crushing

The net control has been taken as zero for ore crushing as it was assumed little if any control equipment has been applied to this operation.

5.4.2 Materials Handling

No information was available that would allow an assessment of the control practices for materials handling operations. An application of control of 35% was assumed for the various sources associated with materials handling and the efficiency of control was estimated to be 90%. Net control therefore is 32%.

5.4.3 Pellet Plants

The emissions were computed for pellet plant by assuming that net control is 75%.

5.4.4 Sinter Plants

Due to the lack of information in the published literature regarding extent of control for the iron and steel industry, and the rapidly changing status of production methods, a phone survey of the integrated iron and steel industry was conducted. This survey requested production quantities plus type and efficiency of control equipment used in the sinter plants, open hearth furnaces, basic oxygen furnaces and electric arc furnaces.

The phone survey contacted 11 companies that operate sinter plants and represented about 50% of the sinter plant production. The phone survey has reaffirmed the fact that this operation always has at least some type of cyclone removal system, operating at relatively high efficiency for recovery and reuse of the dust. Also, one plant has been testing various control methods and found that an electrostatic precipitator would be unsatisfactory because the collected material "fused" to the electrodes and could not be rapped off. The phone conversations have disclosed that the trend toward high flux sinter is creating problems due to the change in particulate electrical resistivity.

The control equipment used on bindbox gases consisted, in almost all plants, of cyclones or cyclones followed by an electrostatic precipitator. However, one plant reported using only a settling chamber. The discharge and control methods usually consisted only of cyclone-type equipment although two plants were using wet scrubbers and another used a baghouse.

Based on the phone survey the application of control and efficiency of control, weighed on the basis of production capacity, have been determined to be 100% and 90%, respectively. Therefore, the net control is 90%. This applies specifically to controls on the windbox but the phone coversations indicate that this may also be representative of the controls used on the discharge end.

5.4.5 Coke Manufacture

The beehive ovens are completely uncontrolled so the net control is 0%. In the by-product coke ovens, essentially all of the particulate matter generated during operation is removed as a consequence of the by-product recovery process. However, the particulate matter generated during the charging, pushing and quenching operations is uncontrolled. Since the emission factors shown in Table 4.1-1 applied only to these emissions, the net control is 0% for the by-product coke ovens.

5.4.6 Blast Furnaces

All blast furnaces have a high control efficiency as the gases must be cleaned for subsequent use as fuel. Any remaining particulate matter becomes a part of the effluent from the fuel user. There is some dust emission that escapes during charging and tapping. Therefore, the efficiency of control has been estimated to be 99% while the application of control is 100%.

5.4.7 Open Hearth Furnaces

The phone survey contacted eight companies that are presently operating open hearth furnaces and this represented 42% of the open hearth production. Several other companies were contacted at which the open hearth furnaces were no longer in operation.

The data obtained in the phone survey showed that the present application of control is 41%. This is considerably higher than reported in earlier literature, due to rapid retirement of many of these furnaces and the increased use of oxygen lancing accompanied by the installation of the control equipment necessitated by this process modification.

All of the open hearths that are presently controlled reported using electrostatic precipitators exclusively. The associated efficiency of control was determined to be 97%.

5.4.8 Basic Oxygen Furnaces

The phone survey contacted 14 companies that operate BOF's and represented over 90% of the BOF production capacity. The information obtained has reaffirmed the data in the Battelle[2/] report showing that all BOF's are equipped with high efficiency control equipment consisting of either a high-energy wet scrubber or electrostatic precipitator. Thus the application of control is 100%. The average efficiency of control is 99% based on actual or estimated efficiencies obtained in the phone survey.

5.4.9 Electric Arc Furnaces

The phone survey contacted 16 companies that operate electric arc steel furnaces and represented 60% of the electric arc steel production.

Earlier data indicated that only 10% of the electric arc furnaces were controlled.[3/] Contrary to this, the phone survey reveals that 79% of the production capacity has control equipment (application of control = 79%). Most of these controlled units employed baghouses. Two plants reported using wet scrubbers and one used an electrostatic precipitator. Based on this information the efficiency of control has been estimated at 99%. However, there is an unknown quantity of fume that escapes collection during charging and other phases of the furnace operation.

5.4.10 Scarfing

No information regarding scarfing operations was included in the phone survey. Literature sources indicate that many plants use a baffled settling chamber,[4/] while others employ electrostatic precipitators or high-energy scrubbers.[5/] Therefore, the efficiency of control has been estimated at 90% and the application of control has been estimated to be 75%.

5.5 Cement

A phone survey was also made of the cement industry and provided data on 47 plants representing 30% of the cement production capacity.

Based on the findings of the phone survey, 94.5% of the production capacity has control equipment on the cement kilns (application of control = 94.5%). The weighted average efficiency of control was found to be 93.6% based on the estimated (or measured) efficiencies of the control equipment installed on the cement kilns covered by the survey. Therefore, the net control was 88%. This was assumed applicable to the calculations of overall emissions from cement plants which included dryers, coolers, and other secondary sources.

The survey revealed that the control equipment on the kilns, for those that do have controls, is as follows:

	Type of Control Equipment on Kilns		
	Mech (only)	ESP or Mech + ESP	FF
% of controlled production capacity using given equipment	18%	65%	17%

5.6 Forest Products

5.6.1 Wigwam Burners

No control is used on wigwam burners, so the net control is 0%.

5.6.2 Pulp Mills

The extent of control, as shown in Table 4.1-1, for recovery furnaces, lime kilns, and dissolving tanks was obtained from personal communication with the National Council for Air and Stream Improvement, Inc. Their data are from a NCASI-NAPCA Kraft pulp industry questionnaire.

Relating to the 33% application of control on dissolving tanks, correspondence from NAPCA concerning the current pulp and paper study provided data, based on 44 questionnaires, indicating that the application of control was about 66%. However, the 44 questionnaires are only about half of the 80 original questionnaires. Therefore, 33% is believed to be the more accurate figure.

The extent of control on recovery boilers for the sulfite and NSSC processes was assumed to correspond with that for the Kraft process. The fluid-bed reactors used in the NSSC process were assumed to be equipped with cyclones operating at an estimated efficiency of 70% per Reference 21.

Net control for bark boilers is not shown in Table 4.1-1 because emissions were calculated separately for boilers with reinjection and for those without reinjection. However, the efficiency of control for the cyclone collectors on bark boilers was estimated at 95% and it was calculated that 75% of the non-reinjection-type boilers also use collectors of 95% efficiency.

5.6.3 Particleboard, etc.

No estimate of net control was made since the method used for calculating the emission qualities did not require this information.

5.7 Lime

A phone survey was conducted to determine the extent of control for the lime production industry, especially the kiln operations. Eleven companies were contacted representing 28 plants or approximately 15% of the total U. S. production. The results of this survey are shown below. It should be pointed out that, for those surveyed, about 80% of the production capacity was by rotary kilns, while the remaining 20% was by vertical shaft kilns.

The control equipment employed on both the vertical and rotary kilns consisted of mechanical collectors, wet scrubbers, or baghouses. The larger plants were usually equipped with wet scrubbers or baghouses.

During the phone conversations, some information was obtained for secondary dust sources. This involves hydrators and other miscellaneous sources. However, the data obtained were not as complete as for kilns. About 80% of the hydrators were controlled at better than 95% efficiency with wet scrubbers or baghouses. The survey also indicated that 80% of the plants had equipment for control of secondary sources. Most used baghouses for this service, while a few just used water sprays. Based on this information, the extent of control for the secondary sources has been determined as shown below.

	Efficiency of Control	Application of Control	Net Control
Lime Kilns (Overall)	93.4%	76.8%	71.8%
Rotary	93.0%	86.8%	80.8%
Vertical	97.1%	40.0%	38.8%
Secondary Sources	95.0%	80.0%	76.0%

5.8 Primary Nonferrous

5.8.1 Primary Aluminum

5.8.1.1 Grinding of Bauxite: A value for net control of 80% has been assumed for grinding of bauxite. No definitive information has been located regarding the controls on grinding but considering the value of this material it seems likely that dust losses would be held to a minimum.

5.8.1.2 Calcining of Hydroxide: A net control of 90% has been assumed for the calcining operation since the alumina contained in the dust should warrant control of dust emissions.

5.8.1.3 Reduction Cells: What little information is available about amounts of particulate from aluminum mills is concentrated about the pot room emissions, as they are the major air pollution source. Pot room emissions can be divided into the roof monitor emissions and the potline control system emissions. The roof monitor emissions are emitted at the building height along the entire length of the building and may be considered a line source of pollution. The scrubber emissions on the other hand are emitted from stacks at a somewhat higher level than the roof emissions, and tend to be placed at one end of the potline building. Actual emissions will vary widely from plant to plant, depending upon the age, the type of cell employed and types of controls. Also an important factor will be the efficiency of hooding over the electrolytic cells, called the capture efficiency.

The aluminum companies have only recently become concerned about particulate emissions. Consequently, little emission testing has been performed and data are scarce or nonexistent. The only data on particulate emissions were obtained from Reference 6. Table 5.8-1 summarizes collection efficiencies for potline control devices, while Table 5.8-2 presents data for roof monitor controls.

Potline controls in Table 5.8-1 are listed according to the type of cell employed because of the varying types and qualities of emissions given off by each cell. Thus, the horizontal stud Soderberg cell only employs spray scrubbers on existing collectors because of the high hydrocarbon content of the cell emissions. The prebake plant, having significantly lower hydrocarbon contents in the cell exhaust, can use multiclones or dry electrostatics ahead of the spray scrubbers to increase particulate removal.

Efficiency of existing controls on potline scrubbers for fluorides ranges between 80 and 90% for total fluorides. Existing particulate control efficiencies are considerably less, varying from 40 to 60%, unless a dry

TABLE 5.8-1

CURRENT AND NEWEST AIR POLLUTION CONTROLS FOR PRIMARY ALUMINUM POTLINE AIR POLLUTION CONTROLS[6]

Type of Cell	Existing Collectors	Est. Removal Efficiencies, %		Latest Collectors	Est. Removal Efficiencies, %	
		Fluorides	Particulates		Fluorides[a]	Particulates
H.S.[b] Soderberg	Spray Scrubbers	80-90	40-50	1. Floating bed scrubber[c]	90	80-90
				2. Wetted plate electrostatic (with conditioning of flue gases)	90	99
Prebake	Multiclones	0	< 60	1. Fluidized alumina contacts cell exhausts, followed by collection in alumina-coated baghouse	99	96-98
	Dry Electrostatic Precipitators		90			
	Spray Scrubbers	80-90	40-50[d] 10[e]	2. Counterflow packed scrubber	90	95
V.S.[f] Soderberg	Multiclones	0	< 60	Sieve Plate Scrubber	95	70
	Spray Scrubbers	80-90	40-50			

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[a] Gaseous and particulate fluorides.

[b] H.S. = horizontal stud.

[c] One section of bed employed.

[d] When used after multiclones.

[e] When used after ESP.

[f] V.S. = vertical stud.

electrostatic is used at estimated particulate removal efficiencies of 90%. (One plant in Washington used dry electrostatics in combination with spray scrubbers.)

Roof monitor controls are listed in Table 5.8-2. The extent to which these devices are currently used on roof monitors is unknown. Collection efficiencies of 60% for fluorides have been estimated, although particulate removal efficiencies are near zero because of their extremely low pressure drop. Another variation of this has been the use of electrostatic prefilters, followed by medium pressure-drop, wetted-mesh, which required a fan to overcome the resistance of the filter. Fluoride emissions collection has been increased to 90% and particulate efficiencies are also increased, although to what extent is not certain.

TABLE 5.8-2

CURRENT AIR POLLUTION CONTROLS FOR ROOF MONITORS[6]

	Collection Efficiency, %	
Type of Control	Fluoride	Particulate
Spray mesh filter	60-70	0
Electrostatic prefilter, followed by wetted mesh filter	90	50[a]

---

[a] Estimated.

The data in Tables 5.8-1 and 5.8-2 have been used to estimate the efficiency of control (particulate only) for the three types of reduction cells as shown below, assuming 80% hooding capture efficiency:

Cell	Estimated Avg. Efficiency of Control Devices	Overall Efficiency (80% capture)
H.S. Soderberg	50%	40%
V.S. Soderberg	80%	64%
Prebake	80%	64%

5.8.1.4 Materials Handling: Control equipment for raw materials handling, if used, are usually cyclones or baghouse. The efficiency of control is therefore estimated to be about 90%. However, it is very difficult to assess the application of these control devices on raw materials handling. It has been assumed that the application of control is 35% for raw materials handling. This duplicates the assumption in the corresponding section on iron and steel.

5.8.2 Primary Copper

5.8.2.1 Ore Crushing: As in the case of iron and steel, it has been assumed that the application of control is 0% for ore crushing operations.

5.8.2.2 Roasting: Roasting in copper smelters is carried out in multiple hearth or fluid-bed roasters. The gases from either type of roaster undergo preliminary solids collection after which they are cooled by air dilution, water sprays or heat exchangers and undergo final cleaning in electrostatic precipitators.7/ Based on this information and personal communication with some of the copper smelters, the application of control is 100%. The average efficiency of the control systems in use is estimated at 85%.

5.8.2.3 Reverberatory Furnaces: Personal communication with an industry source indicates that 80-85% of the reverberatory furnaces are controlled with electrostatic precipitators, operating at an estimated average efficiency of 95%. Net control is therefore 81%.

5.8.2.4 Converters: Reference 8 states that 75-85% of the solids in converter gases settle in the flue system and the remaining portion is largely removed in cyclone collectors or electrostatic precipitators. On this basis, the overall efficiency of control was estimated to be 95% and the application of control was assumed to be 85%, corresponding to that for reverberatory furnaces.

5.8.2.5 Materials Handling: Net control of 32% was used, duplicating the assumed values for iron and steel.

5.8.3 Primary Zinc

5.8.3.1 Ore Crushing: As in the case of iron and steel, it has been assumed that the application of control is 0% for ore crushing operations.

5.8.3.2 Roasting:

(a) Fluid Bed Roasters

In the fluid bed roasters 50 to 85% of the feed to the roaster is carried as dust in the off-gas stream. The gas usually passes through a waste heat boiler where the first increment of dust is collected. More dust is recovered in a cyclone and the gas then flows to an electrostatic precipitator for additional collection.[9]

Since a large portion of the feed material is carried out with the gases from fluid bed roasters, collection systems as described above are required. Thus, the application of control is 100%. An overall efficiency of 98% has been assumed for these collection systems.

(b) Ropp and Multihearth Roaster

Since 5 to 15% of the roaster feed may be carried out of these roasters with the gas stream,[10] it is concluded that the application of control would be 100%. The overall efficiency of control has been assumed to be 85%.

5.8.3.3 Sintering: Usually 5 to 10% of the total feed is carried out as dust in the off-gas from sintering. Recovered dust may be either recycled or treated for lead and cadmium recovery.[11] Thus the application of control is estimated to be 100%, and the efficiency of control is estimated at 95%.

5.8.3.4 Distillation: The application of control is 0% because a small quantity of fume is allowed escape from the condensers in order to prevent the entrance of air. There is also some loss of fume from broken retorts, but the application of control for this is also 0%.

5.8.3.5 Materials Handling: Net control of 32% was used, duplicating the assumed values for iron and steel.

5.8.4 Lead

5.8.4.1 Ore Crushing: As in the case of iron and steel, it has been assumed that the application of control is 0% for ore crushing operations.

5.8.4.2 Sintering: The control equipment used for lead sintering machines is either bag filters or electrostatic precipitators. Collected material is recycled to the sintering machine.[12] It is believed that most sinter operations are controlled, but it is known that at least one unit is uncontrolled.[13] Therefore, the application of control is estimated to be 90%. The overall efficiency of control is estimated to be 95%.

5.8.4.3 Blast Furnaces: The application of control of 98% is based on discussion with a representative of the industry.[13] Baghouses are used to clean lead blast furnace gases. However, operating problems can necessitate bypassing the baghouse,[13] which decreases the overall efficiency. Thus the average efficiency of control has been estimated to be 85%.

5.8.4.4 Dross Reverberatory Furnace: Little information was available on the control equipment associated with the dross reverberatory furnace. Net control of 50% has been assumed for this operation.

5.8.4.5 Materials Handling: Net control of 32% was used, duplicating the assumed value for iron and steel.

5.9 Clay

Very little information was located for the clay industry and associated processes. This industry produces a variety of products entailing different processing steps and these steps may vary, for the same product, depending on the properties of the raw material. Therefore, it is difficult to determine even the quantity of material that is processed.

Phone discussions were held with four of the larger clay products manufacturers in an attempt to clarify these problems and to discuss control practices for the various operations. These manufacturers were helpful but the diversity of practices made it difficult to characterize the individual processes and control practices.

The phone conversations indicated that cyclones and some wet scrubbers are employed in many of the operations but these are mainly for product recovery. On the basis of these few phone conversations, the application of control and efficiency of control have been assumed at the values shown in Table 4.1-1.

5.10 Fertilizer and Phosphate Rock

5.10.1 Phosphate Rock

The emissions from phosphate rock manufacture, as detailed in Section 4.11, come from drying, grinding, calcining and materials handling. The efficiency and application of control was determined on the basis of phone calls and a personal visit with persons in Florida who were very familiar with the current practices for control of phosphate rock operations in Florida. Actual test data on grinders and dryers were obtained as a result of these discussions.

All phosphate rock drying operations are controlled with cyclones and/or wet scrubbers. Data obtained for dryers showed an average efficiency of 94%. All grinding operations are also controlled and similar data showed an average efficiency of 97%.

The emissions from phosphate rock materials handling were assumed to have an application of control of 25% at an estimated average efficiency of 90%.

Some information regarding calcining of phosphate rock was obtained from the Idaho Department of Health. This indicated that all calcining operations were controlled with wet scrubbers at an average efficiency of 95%.

5.10.2 Fertilizers

The computation of emissions from the manufacture of ammonium nitrate, urea and ammonium sulphate were based on the use of a controlled emission factor of 1% of the product. Therefore, the application and efficiency of control were not required for the calculations.

The pulverizing of phosphate rock, associated with fertilizer manufacture, were all assumed to be equipped at least with cyclones and an estimated efficiency of control of 80%.

Interviews with control agency officials and other persons knowledgeable in the field of phosphate fertilizer manufacture in Florida indicated that the application of control was at least 95%. Cyclones and wet scrubbers were used for control of emissions and the average efficiency of control, based on these discussions, was estimated to be 95%.

Private communication with one industrial source provided data on 10 granulation plants. Most of these used cyclones and wet scrubbers at an average efficiency of control of 95%. The application of control, on the basis of these discussions and the data, is estimated to be 95%.

5.11 Asphalt

5.11.1 Paving Material

5.11.1.1 Dryers: Due to the fact that there are some 3,000 asphalt plants in the U. S., a representative phone survey to determine extent of control was not feasible. Therefore, the extent of control has been based on discussions with several members of the National Asphalt Pavement Association. These persons generally represent some of the larger asphalt producers in this country.

Information was obtained from seven companies representing 294 plants and a total production capacity of approximately 25 x 10^6 tons/yr. This production capacity is 10% of the total U. S. production.

All of the plants operated by those seven companies contacted were controlled and the consensus of opinion was that very few plants in the U. S. would have no control at all. When asked, most could not recall any plant that did not have even a primary cyclone on the dryer effluent. Based on these discussions it is estimated that only 1% or less are not controlled. Therefore, the application of control would be 99%.

Only two of the companies contacted had any dryers that were equipped with only a primary cyclone. In both cases, these represented 4 to 5% of their production capacity. The other companies contacted also estimated that only about 5% of all asphalt plant dryers would have only a primary collector.

Based on the above discussions and the data obtained, the following conclusions have been drawn in regard to asphalt plant dryers:

a. 1% of production is uncontrolled.

b. 5% of production is equipped with only a primary collector having an estimated collection efficiency of 70%.

c. 94% of production is equipped with cyclones followed by various types of secondary collectors. The average overall efficiency is estimated to be 98%.

These three conclusions show that the application of control is 99%, and that the weighted average efficiency of control is 96.6%. Therefore, the net control for asphalt plant dryers is 95.6%.

5.11.1.2 Secondary Source: Many asphalt plants duct the emissions from secondary sources to the dryer control system. Since no additional information was obtained about other secondary control systems, the application and efficiency of control were assumed to be the same as for the dryers.

5.11.2 Roofing Materials

5.11.2.1 Blowing: Data on control of emissions from asphalt blowing has not been obtained but a net control of 50% was used as it is estimated that 50% of the particulate emissions from asphalt blowing, in the roofing industry, escapes to the atmosphere.[13]

5.11.2.2 Saturator: The computation of emissions from saturators did not require a determination of the extent of control.

5.12 Ferroalloys

5.12.1 Blast Furnaces

A phone conversation with one ferroalloy blast furnace operator verified that blast furnaces are equipped with high efficiency dust collection systems because the gas stream, which has a high carbon monoxide content, is used as fuel in other parts of the plant. This practice corresponds to that of blast furnaces in the iron and steel industry. Therefore, the application of control is 100% and the efficiency of control is assumed to be 99%.

5.12.2 Electric Furnaces

A phone survey of ferroalloy electric furnace operators was made and covered 11 companies representing 22 plants and 127 furnaces. This represents a production of approximately 1,667,000 tons/yr or 62% of the electric furnace production capacity.

The information requested in the phone survey included:

(a) number of furnaces
(b) KW rating of furnaces
(c) type of hooding (open, closed or hooded)
(d) estimated capture efficiency
(e) type of control equipment
(f) estimated efficiency of control equipment

The calculation of the application and efficiency of control is based on the assumption that production capacity is directly proportional to KW ratings. The calculations are also based on estimated capture efficiency for the various hooding methods. The results of the phone survey for ferroalloy electric furnaces are as follows:

(a) application of control = 49.9%
(b) efficiency of control = 80.5%
(c) net control = 40.2%

5.12.3 Materials Handling

Net control of 32% was used, duplicating the assumed values for iron and steel.

5.13 Iron Foundries

5.13.1 Furnaces

The efficiency of control and amount of control for iron foundries is derived from analysis of a postcard survey of 1,500 foundries conducted by the U. S. Department of Commerce.

The data from this survey revealed that 33.5% of the production had some type of control equipment on the cupolas (based on the value of castings). This survey also showed that 89% of the castings were produced in cupola furnaces.

The survey delineated the cupola control equipment into five types for which we assumed an average efficiency to calculate the efficiency of control. A breakout of the controlled capacity by type of equipment is presented below.

Type of Control Equipment	Assumed Efficiency (%)	Percent of Controlled Capacity
Electrostatic precipitator	97	0.6
Mechanical	75	16.0
Fabric filter	99	9.6
Wet scrubber	90	54.0
Wet cap	50	19.8

From the assumed efficiencies shown above and the percent of the controlled capacity for each type of collector, the average efficiency of control was calculated to be 79.9%. This figure, multiplied by the 33.5% application of control yields a net control of 27%.

5.13.2 Materials Handling

5.13.2.1 Coke, Limestone, etc.: For the handling of coke, limestone and other materials, excluding sand, in the iron foundry operation, it was assumed that the application of control is 25% at an estimated efficiency of 80%.

5.13.2.2 Sand: It was assumed that the application of control was 0% for sand handling operations in iron foundries.

5.14 Secondary Nonferrous

5.14.1 Secondary Copper

5.14.1.1 Material Preparation:

(a) Wire Burning - It was assumed that wire burning is carried out in incinerators without secondary burners and that the application of control is 0%.

(b) Sweating Furnaces - Data in Reference 17 show four sweating furnaces with no control and one furnace equipped with an afterburner and baghouse. This indicates an application of control of 20% and the efficiency of control was estimated to be 95%.

(c) Blast Furnace - Data from Reference 17 show four cupolas (blast furnaces) equipped with baghouses, one with a wet collector and one uncontrolled. This is based on questionnaires completed by members of the Brass and Bronze Ingot Institute whose twelve member plants represent 40% of the production. Using the above data and assuming that BBII members may have somewhat better control practices, the application of control was estimated to be 75%. Overall efficiency of control for the devices used on cupola furnaces was estimated at 90%.

5.14.1.2 Smelting and Refining: Reference 17 shows the capacity of several reverberatory and rotary furnaces and their associated control equipment. The reverberatory furnaces represent 80% of the capacity shown and 71% of the reverberatory capacity is controlled while 80% of the rotary furnaces are controlled. Again, these data represent members of the Brass and Bronze Ingot Institute. Thus, the overall application of control is estimated to be 60%.

All of the controlled furnaces, discussed above, were equipped with baghouses. However, the capture efficiency for the hooding arrangements have been considered in estimating the efficiency of control at 95%.

5.14.2 Secondary Aluminum

5.14.2.1 Sweating Furnaces: Due to lack of information about secondary aluminum control practices, the net control was assumed identical to that for secondary copper sweating furnaces.

5.14.2.2 Refining Furnaces: Net control was assumed identical to that for secondary copper refining furnaces.

5.14.2.3 Chlorine Fluxing: It has been stated[18] that the collection of aluminum chloride and aluminum oxide particulates from chlorine fluxing has defied conventional means of control. Bag filters become plugged by the hydroscopic aluminum chloride and low energy scrubbers do not have adequate collection efficiency, meaning that an unacceptable plume appearance will remain.

Due to this difficulty of control it has been assumed that 75% of the particulate generated escapes to the atmosphere. Correspondingly, net control would be 25%.

5.14.3 Secondary Lead

Very little information has been available on secondary lead operations and control practices. However, considering the toxicity of the fume it seemed logical that the degree of control would be fairly high. Personal communication with one industry source indicated that almost all furnaces are controlled with baghouses. Thus, the application of control has been assumed to be 95% and the overall efficiency of control has been estimated at 95% for the three types of furnaces..

5.14.4 Secondary Zinc

5.14.4.1 Sweating Furnaces: Due to lack of information about secondary zinc control practices, the extent of control was assumed identical to that for secondary copper sweating furnaces.

5.14.4.2 Distillation Furnaces: The extent of control figures for zinc distillation furnaces was assumed identical to that for secondary copper smelting and refining furnaces.

5.15 Coal Cleaning

The computation of emissions from thermal dryers, as detailed in the specific industry section of this report, was based on average outlet grain loadings from the various control systems. Thus, it was not necessary to determine an average efficiency of control but it is pointed out that all dryers are equipped at least with cyclones and many plants have wet scrubbers following this cyclone.

5.16 Carbon Black

5.16.1 Channel Process

The application of control is 0% because control measures would upset the burning conditions and drastically affect yield and quality.[19]

5.16.2 Furnace Process

The furnace process utilizes control equipment as a part of the process to collect the product. The computation of emissions, as detailed in the specific industry section of this report, makes use of controlled emission factors from this equipment. The controlled emission factor of 60 lb/ton for the gas process is based on 97% overall collection efficiency for cyclones followed by a scrubber.[20] The controlled emission factor of 10 lb/ton for the oil process is based on 99.5% overall collection efficiency for a fabric filter system.[20]

5.17 Petroleum

The largest source of particulate emission from refineries (exclusive of flare systems) is the dust from fluid catalytic cracking units. All of these employ two or three states of cyclone separators and some follow this with additional cleaning in electrostatic precipitators. Thus, the average efficiency exceeds 99.9%. This makes it impractical to calculate the emissions on the basis of an uncontrolled emission factor which would require an accurate determination of this high level of control. Therefore, the emissions were computed on the basis of a controlled emission factor, as detailed in Section 4 of this report.

5.18 Acids

5.18.1 Sulfuric Acid

(a) Chamber Process - The application of control is 0% for the gases exit the final Gay Lussac tower.[15]

(b) Contact Process - Control devices for contact processes include electrostatic precipitators, glass-fiber and wire-mesh eliminators. The electrostatic precipitators are capable of 92 to 99.9% efficiency. Glass-fiber mist eliminator efficiencies range from 94 to 99.9% while typical efficiencies for wire-mesh eliminators may be 93%.[14] Based on this information and data presented in Reference 14, the efficiency of control is estimated to be 95%.

No definitive information was located that would allow a reliable determination of the percentage of the plants that have installed control devices. Considering the relative simplicity and efficiency of the mesh-type mist eliminators that are available, and the value of the recoverable mist, we have roughly estimated the application of control to be 90%.

(c) Acid Concentrators - Very little information has been found pertaining to acid concentrators and associated control devices. It has been stated[15] that emissions from the vacuum-type concentrators are minor. The drum-type concentrators may use electrostatic precipitators, venturi scrubbers, or glass-fiber mist eliminators.[15]

A phone conversation with one designer of spend acid concentrators indicates that a large majority of these units are equipped with electrostatic precipitators or venturi scrubbers. Without further information, the application of control has been estimated at 85% and the efficiency of control estimated to be 95%. Thus, net control is 80%.

5.18.2 Phosphoric Acid (Thermal Process)

The report "Atmospheric Emissions from Thermal-Process Phosphoric Acid Manufacture."[16] gives information on 90% of the thermal process establishments in the U. S. All of these have control equipment. Reference 16 states that "Losses of phosphoric acid to the atmosphere represent direct product loss; therefore, efficient collection devices are normally installed in the gas stream before the gas is discharged from the plant."[16] It is concluded from this that the application of control is 100%.

The data given in Reference 16 show the collector efficiencies ranging from 95 to 99.9%. The efficiency of control is at least 97% although data were not given on some of the plants.

5.19 Emissions Based on an Annual Average Efficiency

The efficiency of control determined for each of the major industrial sources is based, for the most part, on estimated equipment efficiencies, because most plants have not tested their equipment to determine actual operating efficiencies. These estimates of efficiency tended to be near the higher end of the efficiency ranges for each type of control device and, therefore, are more representative of the optimum efficiency for these devices. The emissions shown in Table 4.1-1 were calculated using these estimated efficiencies although it might be assumed that actual collection efficiencies would be somewhat lower because of equipment malfunctions.

A decline in the efficiency of control devices over a period of time may result from a variety of operational problems: cyclones may plug up, wet scrubbers may scale up, filter bags become abraded and torn, and electrostatic precipitators may have sections short out or may not maintain peak voltage adjustment. When these problems or others require maintenance, the control device may be taken off the line without shutting down the process. The increased emissions which result from the above problems and practices result in a lower average control efficiency on an annual operating basis.

In addition to the reasons cited above for decreased operating efficiency of the control devices, many of these installations include various hooding arrangements which rarely capture all of the fume that is emitted by the source. An example of this is the hooding systems installed on electric furnaces in the iron and steel industry. Although the fume that escapes collection by the hoods appears to be significant, no information is available on the quantity or percent of fume that is not captured.

Considering all of the above factors and other problems that lead to decreased collection efficiency, the emissions from each of the industrial sources might reasonably be computed on the basis of an annual average efficiency that is lower than the more optimum efficiency estimates discussed in the preceeding sections and used in Table 4.1-1. A computation of emissions using this lower annual average efficiency would be useful for comparison purposes as an estimate of the maximum quantity of particulate emissions that might be expected from any of the industrial sources. A calculation of this type and the results are given in Appendix C.

5.20 Reliability of the Determined Values for Application of Control

The percentage application of control for each industry and source has been determined by methods explained in the preceding sections. Many of these were based on phone surveys while others were only estimates. The phone surveys probably represent the best method of assessing the application of control, but the reliability of even this method would be improved if the phone survey could have covered a much larger percentage, such as 90% or more, of the production capacity of each industry group. Also, most of the survey information collected was representative of the larger companies. These companies were contacted first since they comprise a large percentage of the production capacity. Time and money limitations restricted more extensive survey work. The fact that the surveys tend to represent practices of the larger companies, may decrease the reliability of the values for application of control on the basis of the assumption that these larger companies may be more progressive in their control practices.

Considering the various factors that restrict the reliability of the values used for the percentage application of control, Table 5.20-1 has been prepared as a guide to indicate our best judgment of the relative reliability of these values for each industry group. An arbitrary rating system for these values is given below. The actual method of obtaining the percentage application of control for each industry is explained in the preceding sections of this chapter.

Excellent Reliability - Process information which leaves little doubt as to the control practices.

High Reliability - Survey of the industry, which, in our own judgment, is representative of the industry. Usually the survey will have covered over 50% of the production capacity.

Good Reliability - Survey of the industry, covering less than 50% of the production capacity, which we feel is probably representative of the industry.

Fair Reliability - Some survey data or industry reports were used to assess the application of control.

Minimum Reliability - An estimate of the application of control that has the lowest reliability.

TABLE 5.20-1

RELIABILITY OF VALUES FOR "APPLICATION OF CONTROL"

Industry Group	Reliability of Values for Percentage Application of Control
1. Fuel combustion	
A. Coal	
1. Electric utility	
a. Pulverized	High
b. Stoker	High
c. Cyclone	High
2. Industrial boilers	
a. Pulverized	High
b. Stoker	Good
c. Cyclone	Fair
2. Crushed stone, sand and gravel	Minimum
3. Operations related to agriculture	Fair
4. Iron and steel	Good
5. Cement	High
6. Forest products	Good
7. Lime	High
8. Primary nonferrous metals	Fair
9. Clay	Fair
10. Fertilizer and phosphate rock	Good
11. Asphalt	Good
12. Ferroalloys	High
13. Iron foundries	High
14. Secondary nonferrous metals	Minimum
15. Coal cleaning	Excellent
16. Carbon black	Excellent
17. Petroleum	Excellent
18. Acids	
A. Sulfuric	Minimum
B. Phosphoric	High

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6. RANKING OF AIR POLLUTANTS AND THEIR SOURCES BY OBJECTIONABLE PROPERTIES

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6.1 Introduction

The ranking of air pollutants and their sources on the basis of "objectionability" is quite difficult for several reasons including the following: the dissimilarity of properties which are considered objectionable; the highly subjective nature of much of the available data; and the unavoidable dependency of the "objectionability" on the geographical and meteorological relationships of the source and receptors. By definition an objectionable property of a pollutant is one which causes objections from humans because it produces an undesirable effect on some type of receptor (animal, plant, or material). An objectionable source is one which emits one or more of these objectionable pollutants in a location where they can cause one or more of these effects. The reasons for the objections may range from the homemaker's concern over soot and fly ash settling out of the atmosphere to the geophysicist's concern over the CO_2 and particulate levels which are increasing in the atmosphere.

The effects of air pollution have been reviewed[1-5] in terms of physical properties of the atmosphere, vegetation, biological systems, human health, and materials and the economy. A brief outline of the objectionable properties of air pollutants and the affected receptors would include:

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1. Toxicological and Sensory Effects on Humans
    a. Acute Toxicity
    b. Chronic Toxicity
    c. Irritation of Eyes, Lungs, Mucous Membranes, Skin, etc.
    d. Odor
2. Effects on Plant and Animal Life
    a. Toxic to Agricultural Crops, Timber, Grass
    b. Toxic to Livestock and Wildlife
3. Effects on Materials and Facilities
    a. Soiling
    b. Corrosion of Metals, Minerals, Plastics, Textiles and Paint
    c. Effects on Electrical Systems
    d. Miscellaneous (abrasive, forms sludges, etc.)
4. Optical and Esthetic Effects
    a. Reduces Visibility
    b. Produces Visible or Colored Plume or Colored Atmosphere

Some of these areas are of much less significance to the present program on particulates than to the overall air pollution problems as will be discussed in the next paragraph. Also a broad distinction must be made between the pollutant in the immediate vicinity of the source (where it is present in high concentration) and the pollutant in the atmosphere (where it is present in lower concentration and is well removed from the vicinity of the source). In the former case, a knowledge of stack height and emission data, wind direction and speed, etc., are important variables, but in the latter, the meteorology of the air basin may be a major factor.

In regard to the specific area of particulate pollutants from stationary sources, several of the above categories are of marginal pertinence. For example, malodorous effluents are highly objectionable air pollutants, but they consist largely of gaseous, rather than particulate materials, although the odorous compound may also interact with the solid particles (e.g., be absorbed, transported, and released), or be in solution in liquid mists. The distinction between the particulate matter and the carrier gas in the effluent is difficult to make. Similarly, the irritants are largely the gaseous compounds, such as the SO_x and NO_x compounds, rather than particulates. Haze formation and photochemical smog are closely tied to automobile exhaust which is excluded by the stationary source criteria. Nevertheless, some consideration of each category is required in the present study.

6.2 Methods of Ranking

The ranking of air pollutants by their effects on receptors can be approached by several methods. Ideally, one would like a ranking system which relates the two factors involved: properties of the source of a pollutant and properties of the pollutant which make the pollutant objectionable to the various receptors. Thus, rating systems based on total tonnage of emission would consider only one property of the source, whereas tabulations of maximum allowable concentrations for occupational exposure to airborne pollutants consider only a portion of the properties of the pollutants on only one of the receptors. An objectionability rating of pollutants should include all physiological, economic and esthetic factors. A true objectionability rating of sources must consider not only the total tonnage of particulate emitted, but also the size distribution and the chemical composition of the particles, and the composition of the carrier gas, since pollutants which are emitted as gases may either remain as gases or be converted into respirable particles by the time they reach the receptor. This last comment illustrates that the objectionability of a given source is dependent on atmospheric events between the source and the receptor. Obvious factors then which influence objectionability of a source include the manner in which the pollutant is emitted (i.e., continuous source of low strength versus an intermittent source of high strength) the dispersion of the pollutant before it reaches the receptor (including stack height, meteorological and geographical conditions, and atmospheric reactions) and the location, density or nature of the surrounding population, vegetation or structures, i.e., the receptors. In order to place the rating system on some objective basis the quantification of several parameters is required.

6.3 Ranking on the Basis of Complaints

Local pollution problems frequently result in objections from the afflicted populace. The various city, county, regional or state pollution control agencies have received these complaints and have generally filed and tabulated them according to various categories, e.g., name and location of complaintant, character of pollutant, source of pollutant, etc. Typical data from two air pollution control agencies are shown in Table 6.3-1. Unfortunately the agencies do not use the same categories so that comparisons and summaries are difficult. As part of the information gathering phase of this program, a survey was made of air pollution control agencies to determine problem sources in various areas of the country. One question of the questionnaire asked the agencies to identify particulate sources that have caused complaints in their communities. This question was as follows:

> Question 5. Please list 5-10 particulate (solid or aerosol) sources of air pollution in your community that have caused complaints and possible or definite effects.

	Source	Effect or Damage
Examples:	Pesticide Manufacture	Vegetation damage
	Carbon black Manufacture	Soiling

A total of 580 "problem source" complaints were noted by by 113 agencies (located in 42 different states) which responded to the questionnaire. A total of 775 complaints by effects or damage were specified. The results* of this survey are summarized in Table 6.3-2.

The primary metals industries and the stone clay and glass products industries are the biggest source of complaints, followed closely by petroleum-related industries and refuse disposal. Asphalt plants are the largest single source.

Discussions with personnel at pollution control agencies revealed several points which influence the number and types of complaints from the populace. In particular, the major complaint is almost invariably that of soiling by particulate matter (dust, soot, etc.) while complaints about odors generally rank next. These effects and the visible sightings of smoke are readily recognized and described by the average citizen. Other effects, such as corrosivity or toxicity are not recognized by the general public unless they are of large or catastrophic proportions and are not so frequently reported.

The responses on odor complaints were probably limited in our survey by the emphasis placed on particulates in the questionnaire. The results of a survey on sources of objectionable odors have been reported and are shown in revised form in Table 6.3-3. The irritant characteristics of air pollution are illustrated by the California survey results shown in Table 6.3-4. In both of these cases the major pollutants causing the complaints are gases, but the results are included in this review for illustrative purposes.

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* The results also showed geographical variations not illustrated in Table 6.3-2, e.g., the high percentage of complaints on sawmills, Table 6.3-1A, would not be true in states with little forest industries.

TABLE 6.3-1

TYPICAL AIR POLLUTION COMPLAINTS FROM THE PUBLIC

A. Source & Character of Air Pollutants Which Caused Complaints in Wisconsin (1968-69)

Source	Complaints	Source	Complaints
Open Burning Dumps	18%	Paving Plants (including asphalt, gravel, etc.)	6%
Foundries	15%		
Sawmills	9%	Rendering Plants	6%
Fertilizer	8%	Coal, etc. (stockpiling and conveying)	4%
Diesel Smoke	8%		
Power & Heating Plants	7%	Cement	2%
Pulp and Paper	6%	Incinerators	2%

Character	Complaints
Particulates (fly ash, etc.)	32%
Odors (incl. Mercaptans)	30%
Smoke and Soot	28%
Gases (NH_3, NO_x, etc.)	10%

B. Air Pollution Complaints Received in Minneapolis

Character	Complaints 1964	Complaints 1966
Odors	35%	26%
Dust, Soot, Fly Ash	18%	23%
Smoke	45%	50%
Miscellaneous	2%	1%

TABLE 6.3-2

COMPLAINTS MENTIONED BY AIR POLLUTION CONTROL AGENCIES RESPONDING TO MRI SURVEY

	Agencies Reporting Complaints							
	By Source		By Effect					
Problem Source	Number	% of Total	Property Damage	Odor	Animal and Vegetation Damage	Toxic to Humans	Nuisance, Visibility, etc.	Totals and % of Total
Primary Metal Industries								
Foundries (general)	28		23	1	3	2	9	38
Steel	16		10	2	-	1	4	17
Aluminum	14		6	1	5	1	8	21
Brass, Zinc, Copper, etc.	20		12	6	5	5	10	38
Subtotals	78	13%	51	10	13	9	31	114 (15%)
Stone, Clay and Glass Products								
Cement	25		23	-	2	1	7	33
Rock grinding	11		9	-	1	2	3	15
Rock quarry	11		8	-	1	1	6	16
Concrete mix	8		5	-	-	-	1	6
Phosphate rock	6		2	-	4	1	1	8
Gypsum, perlite, etc.	22		16	3	1	2	10	32
Subtotal	83	14%	63	3	9	7	28	110 (14%)
Petroleum Refining and Related Industries								
Asphalt Plants	55		40	7	2	3	18	70
Petroleum Refineries	6		3	3	2	-	2	10
Roofing Manufacturing	5		4	4	-	-	4	12
Subtotal	66	11%	47	14	4	3	24	92 (12%)
Refuse Disposal								
Incinerators	30		18	4	-	1	6	29
Open Burning Dump	19		18	8	1	1	7	35
Backyard Burning	9		-	-	-	-	-	-
Junked Auto	7		6	3	-	-	3	12
Miscellaneous	3		6	4	-	-	3	13
Subtotal	68	12%	48	19	1	2	19	89 (11%)
Chemicals and Allied Products								
Fertilizer	14		9	2	6	-	4	21
Chemical (general)	13		8	6	6	1	2	23
Pesticides	5		-	4	2	4	-	10
Soap and Detergent	3		-	1	-	-	2	3
Ammonia, Sulfuric Acid, etc.	10		2	3	3	2	2	12
Carbon	9		4	2	-	-	1	7
Subtotal	54	9%	23	18	17	7	11	76 (10%)
Agriculture								
Grain Handling	9		11	1	-	4	5	21
Wood Waste Burners	7		3	-	-	-	1	4
Cotton Gins	5		2	-	-	-	2	4
Agricultural Burning, Frost Protection, etc.	22		15	7	2	-	8	32
Subtotal	43	7%	31	8	2	4	16	61 (8%)
Forest Products								
Lumber Products	9		3	-	-	-	2	5
Plywood, Sawmills, etc.	13		14	-	1	1	6	22
Pulp and Paper	14		7	8	2	-	2	19
Box Manufacture	1		1	1	-	-	-	2
Subtotal	37	6%	25	9	3	1	10	48 (6%)
Electric Utilities	38	7%	25		3	3	8	39 (5%)
Food and Kindred Products								
Grain Mills	17		5	2	-	-	2	9
Rendering	5		-	2	-	-	-	2
Tobacco, Sugar, Coffee, etc.	17		6	11	-	3	3	23
Subtotal	39	7%	11	15	-	3	5	34 (4%)
Construction	13	2%	16	3	1	1	5	26 (3%)
Miscellaneous	61	11%	44	7	6	7	23	87 (11%)
TOTAL	560		384	106	59	47	180	776
% by Effect			49%	14%	8%	6%	23%	

TABLE 6.3-3

RANKING OF SOURCES OF OBJECTIONABLE ODORS BY COMPLAINTS RECEIVED

Source			Percent of Complaints[a]
Meat packing and rendering plants			8.2[b]
Gasoline and diesel engines			6.8
Solid waste combustion (incinerator, open burning, etc.)			6.2
Foundries and smelters			6.2
Steel mills, combustion, coke-oven and coal gas			6.2
Coffee roasting			5.5
Paint, lacquer and varnish manufacture			5.5
Refineries			4.8
Asphalt roofing and paving, manufacture and use			4.8
Restaurants and bakeries			4.8
Organic waste decomposition (acids, protein, lignite, etc.)			4.1[b]
Sewers and sewage treatment plants			3.4
Manufacturing plants producing "fish-oil" (amine) odors			3.4
Paint spraying			2.7
Poultry ranches and processing			2.7
Fertilizer plants			2.7
Maladjusted heating systems			2.0
Plastics manufacture			2.0
Dry cleaning shops			2.0
Rubber burning (smelting and debonding)			2.0
Unidentified (industrial)	Hydrogen sulfide	4.8	
	Sulfur dioxide	2.7	
	Ammonia	2.0	
	Commercial solvents	2.0	11.5

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a/ Condensed from data reported in Reference 6, Chapter 8 (based on 146 complaints recorded in a 1958 survey).

b/ Some complaints recorded as waste decomposition were probably related to meat processing plants.

TABLE 6.3-4

CALIFORNIA SURVEY OF AIR POLLUTION COMPLAINTS[a]

Effects Reported[b]	% of Respondents' Complaints[c]			
	Los Angeles and Orange Counties	San Francisco Bay Area	Rest of State	Total California
Eye irritation	90	60	37	76
Nasal irritation	25	14	11	20
Breathing	11	13	12	12
Headache	3	1	3	3
Throat irritation	3	3	4	3
Cough	2	4	1	2
Sinus	1	2	5	2
Odor	2	14	9	5
Annoyance	5	14	24	10
Miscellaneous	0.5	2	3	1
Unspecified	0.5	5	13	3

a/ Results of a 1960 survey condensed from Reference 4, p. 607.

b/ Question: (Asked only of persons who reported being bothered by air pollution.) "How does it bother you--in what ways?"

c/ Many respondents reported more than one effect, so the percentages add to more than 100.

6.4 Ranking of Pollutants on the Basis of Increase Over Background

One approach to the rating of pollutants which man has emitted into the atmosphere would be to compare levels observed with those of the "natural" background; i.e. in the absence of those activities of man which have caused significant pollution.* This type of data, however, is of limited availability.[6-10] The National Air Sampling Network has, since 1957, been collecting certain analytical data on various pollutants at urban and "nonurban" stations and has recently[10a,10b] tabulated data at nonurban stations for a number of metals and other pollutants. Stern has also estimated[11] some so-called "global" backgrounds for CO, SO_2, NO_2, oxidant or ozone, terpenes (olefins), sulfate and nitrate. The NASN data show considerable variation among reporting stations, and air quality at some "nonurban" sites is obviously influenced by metropolitan areas. One would, of course, expect that local background levels would be influenced by local variations in mineral content, vegetation, wind conditions and proximity to the ocean, and the NASN data appear to reflect some of these effects. Based on the NASN data and consideration of the abundance[12] and distribution of the chemical elements in the ocean and in the earth's crust (Table 6.4-1) we have developed a set of normal background levels for the United States* (as shown in Table 6.4-2).

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* This "natural" background may vary slightly from so-called "global" backgrounds or backgrounds determined at isolated points on the earth.

Urban levels of several of these pollutants have been measured for several years and the arithmetic mean and also the maximum observed values have been previously reported.[6] These are reported in Table 6.4-3 (together with some supplementary data). The ratio of these observed levels to background levels then might be called a "pollution factor." Table 6.4-4 shows a ranking of these pollutants on the basis of the pollution factors. Not shown by these data but of serious concern is the increase of rural background levels of total particulates compared to the normal background used herein.

6.5 Ranking on the Basis of Toxicity

The ranking of pollutants and sources on the basis of toxicity is extremely difficult. The toxicity depends not only on the chemical elements present, but also on the chemical compounds or species which are present,** their physical properties (such as particle size, crystal modification in some cases, volatility and solubility), the nature of the receptor and the route by which the pollutant enters the receptor.*** A true measure of the objectionability of various kinds of air pollutants could be provided only by a knowledge of their toxicity to all kinds of life under all kinds of conditions, but obviously this type of information is lacking. Lave and Seskin[14] have attempted to quantify the effects of air pollution on human health and to estimate the dollar benefits of pollution abatement. Extensive literature on toxicity of air pollutants is available, but evaluation is exceedingly difficult. The lack of toxicity data for long-term exposure to low levels of pollutants has slowed the setting of uniform air quality standards for all the possible airborne pollutants. Thus, those which have been set by various agencies in this country and by governmental agencies in other countries frequently show variations of one or two orders of magnitude.

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* These data appear to fit best the observed data at the NASN nonurban sites in Nebraska and South Dakota.

** A stark contrast is presented by $HgCl_2$, a violent poison, and Hg_2Cl_2 (calomel) which has been used as a laxative (although toxic in large quantities).

*** The high toxicity of inhaled mineral oil mists contrasts with its very low toxicity by ingestion.

TABLE 6.4-1

AVERAGE ABUNDANCE OF SELECTED ELEMENTS IN THE EARTH'S CRUST

Element[a]	Abundance[12] ppm	Rank
Metals		
Manganese	1000	10
Rubidium, Strontium, Barium	310-250	16, 18, 19
Zirconium	220	20
Chromium, Vanadium, Zinc, Nickel, Copper	200-70	21-25
Tungsten	69	26
Cerium	46	29
Tin	40	30
Cobalt	23	23
Lead	16	36
Gallium	15	37
Molybdenum	15	38
Thorium	12	39
Germanium	7	41
Beryllium	6	44
Arsenic	5	47
Uranium	4	50
Antimony	1	58
Mercury	0.5	62
Bismuth	0.2	64
Cadmium	0.15	66
Non Metals		
Phosphorus, Sulfur, Carbon	1180; 520; 320	11, 13, 14
Chlorine, Fluorine	310, 300	15, 17
Nitrogen	46	28
Bromine, Iodine	1.6, 0.3	55, 63
Selenium	0.09	69

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[a] Ten major elements not listed: O, Si, Al, Fe, Ca, Na, K, Mg, Ti, H (in decreasing order).

TABLE 6.4-2

ESTIMATED NORMAL BACKGROUND LEVELS OF VARIOUS AIR POLLUTANTS IN THE UNITED STATES

Pollutants	Background $\mu g\ m^{-3}$ each
Total Suspended Particulate	20-40
Aluminum; Calcium; Phosphate; Carbonate; Silicate Minerals	1-5
Chlorides; Fluorides; Sulfates (salts)	0.5-1.0
Iron; Salts of NO_3^-	0.2-0.5
Magnesium; Salts of NH_4^+	0.1
Copper; Manganese; Titanium; Zinc	0.01
Arsenic; Barium; Gallium; Germanium; Rubidium; Strontium	0.005
Chromium; Lead; Nickel; Selenium; Tin; Vanadium; Zirconium	0.001
Cerium; Mercury; Molybdenum; Thorium, Tungsten	0.0005
Antimony; Beryllium; Bismuth; Cadmium; Cobalt; Uranium	0.0001
Miscellaneous Organic (combustible) Particulates and Liquid Particulates	10
Benzene-soluble organics (excludes pollens, molds, etc.)	1
Benzo(α)pyrene (carcinogen)	0.0001
Gaseous Pollutants*	
Carbon Monoxide	100
Misc. Organics (excluding CH_4)	100
Terpenes, other olefins, aldehydes (total)	50
Ozone and peroxides (total)	50
Nitrogen Oxides	40
Ammonia	10
Inorganic acids (total HCl, HF, HNO_3, H_2SO_4, H_3PO_4)	10
Sulfur Oxides	5
Hydrogen Sulfide	1

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* Excludes 300 ppm CO_2, 1 ppm CH_4 and 0.5 ppm N_2O normally present.

TABLE 6.4-3

TYPICAL URBAN LEVELS OF POLLUTANTS IN THE AIR

Pollutant	Arith. Mean[a] ($\mu g\ m^{-3}$)	Max.[a] ($\mu g\ m^{-3}$)
Metals		
Beryllium	< 0.0005	0.010
Bismuth	< 0.0005	0.064
Cobalt	< 0.0005	0.060
Antimony	0.001	0.160
Cadmium	0.002	0.42
Molybdenum	< 0.005	0.78
Chromium	0.015	0.33
Arsenic	0.02, < 1	2.4
Tin	0.02	0.50
Nickel	0.034	0.46
Titanium	0.04	1.10
Vanadium	0.05	2.20
Copper	0.09	10.00
Manganese	0.10	9.98
Mercury	0.1	14
Zinc	0.67	58.0
Lead	0.79	8.6
Phosphorus	1	Not Available
Iron	1.58	22.0
Inorg. Salts		
Ammonium	0.7	4.3
Nitrates	2.6	39.7
Sulfates	10.6	101.2
Organics		
Benzene-soluble	6.9	17.1
Benzo(α)pyrene	2.8×10^{-3}	11.2×10^{-3}
Total Suspended Particulates	105	1254
Gaseous Pollutants		
SO_2	62	346
NO_2	141	333
Carbon Monoxide	~ 7000	-
Hydrocarbons (excl. CH_4)	~ 500	-
Oxidants	~ 100	-
Ammonia	~ 80	250
HCl	~ 70	-
HF	~ 8	-
H_2S	~ 4	-

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[a] Arithmetic mean and maximum urban particulate concentration in the U.S. 1960-1965, from Reference 6 except As, Hg and P from Reference 13, NH_4^+ and organics from Reference 10b, and gaseous pollutants from NASN and miscellaneous sources.

TABLE 6.4-4

RANKINGS OF URBAN AIR POLLUTION LEVELS COMPARED TO NORMAL BACKGROUND LEVELS

Ranking	Pollutant	Average Pollution Factor (Mean)/(Background)	Max. Pollution Factor (Max.)/(Background)
1	Lead	790	8,600
2	Mercury	200	28,000
3	Carbon Monoxide	~ 70	-
4	Zinc	67	5,800
5	Vanadium	50	2,200
6	Nickel	34	460
7	Benzo(α)pyrene	28	110
8	Cadmium	20	4,200
9	Tin	20	500
10	Sulfates	20	200
11	Chromium	15	330
12	Sulfur Dioxide	12	70
13	Antimony	10	1,600
14	Manganese	10	1,000
15	Nitrates	10	200
16	Molybdenum	10	1,560
17	Copper	9	1,000
18	Iron	8	110
19	Ammonia	8	25
20	Ammonium Salts	7	43
21	Benzene-soluble organics	7	20
Unranked			
"	Bismuth	5	640
"	Cobalt	5	600
"	Arsenic	4	480
"	Titanium	4	110
"	Beryllium	5	100
"	H_2S, NO_2, Oxidant, Hydrocarbons, Aldehydes	5	-
"	Total Suspended Particulate	4	50

Studies of the toxicity of pollutants to other animal life have centered on the usual laboratory test animals which are frequently the basis of judgment of the toxicity of the material for humans. On the other hand, toxicology data are frequently found to be species-specific. Studies of the effects of pollutants on wild life are really just getting under way and an attempt to rank pollutants on this basis is not justified at present.

The phytotoxicity of pollutants shows a much greater range of variation than does human toxicity. Some species of plants show an extreme sensitivity to specific pollutants while others tend to accumulate elements, such as selenium, arsenic and fluorine, and thereby become highly toxic to livestock. Brandt and Hech[2/] have reviewed the complex relationships of sensitivity with time and intensity of exposure, species and varietal differences, soil and weather factors, synergistic effects, and mode of attack by the pollutant. In general, the objectionable pollutants are small gaseous molecules such as ethylene, oxidants (O_3, PAN, NO_2,* Cl_2), acids (HF, HCl, H_2SO_4, etc.), bases (NH_3, N_2H_4), and SO_2 rather than particulate matter and will not be ranked here.

The American Conference of Governmental Industrial Hygienists sets threshold limit values (TLV's) for industrially important chemical compounds which may be involved in occupational exposure. The TLV's (based on human and animal toxicology studies and industrial experience) give those levels of airborne gases, mists or dusts to which nearly all workers of normal health can be repeatedly exposed, day after day during a normal work week, without apparent adverse effect. These TLV's are not directly applicable in considerations of air pollution where the population contains many susceptible individuals who would be subjected to possibly prolonged exposures. Thus, the annual exposure of the general populace to the atmosphere is about 4.4 times greater than the occupational exposure of the worker. Probably even more important would be the build-up of the body burden of specific pollutants because the excretion rate does not maintain pace with the intake rate under constant exposure. Also of very great importance, but not considered by the TLV's, is the size distribution of the particles, which has a marked effect on the extent to which respired particles are retained by the body and the location in the respiratory system in which they are active. Nor do they consider synergistic effects. The TLV's do, however, provide one guide to the relative toxicities of various pollutants to humans, which we believe can be used in the present study.

Table 6.5-1 presents selected TLV's for a number of elements and compounds.[15/] In selecting these entries, emphasis was placed on the industrially important metals, but a number of other entries are included because they are prevalent, or for comparative purposes. (Data are not available on all the commercial inorganic compounds, let alone the probable

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* PAN, peroxyacetyl nitrate.

TABLE 6.5-1

RELATIVE TOXICITIES OF POTENTIAL AIR POLLUTANTS

(Selected TLV's for Toxic Dusts, Fumes and Mists[a])

Substance	TLV (mg m^{-3})
Extremely Toxic	
Beryllium	0.002
Platinum, soluble salts	0.002
Silver, metal and soluble compounds	0.01
Mercury, vapor, inorg. and org. compounds (except alkyl Hg, 0.01)	0.05
Methyl isocyanate	0.05
Highly Toxic	
Lead, tetraethyl	0.1 (as Pb)
Cadmium oxide fumes	0.1 (as Cd)
Chromic acid and chromates	0.1 (as CrO_3)
Cobalt, metal fume and dust	0.1
Vanadium, V_2O_5 fume	0.1
Lead arsenate	0.15
Lead, tetramethyl	0.15 (as Pb)
Lead	0.2
Cadmium metal dust and soluble salts	0.2
Coal tar pitch volatiles	0.2
Ozone	0.2
Quartz, fused silica, crystobolite, tridymite	0.1-0.3[b]
Selenium compounds	0.2 (as Se)
Uranium compounds	0.2 (as U)
Very Toxic	
Antimony and compounds	0.5 (as Sb)
Arsenic and compounds (except AsH_3, 0.2)	0.5 (as As)
Barium, soluble compounds	0.5
Chromium, soluble salts	0.5 (as Cr)
Vanadium, V_2O_5 dust	0.5
Nicotine	0.5
Bromine (Br_2)	0.7
Ammonium chloride fume	1
Calcium arsenate	1
Chromium, metal and insoluble salts	1
Copper, fume, dusts and mists	1
Cotton dust (raw)	1
Hydrogen peroxide	1
Iron, soluble salts	1 (as Fe)
Iron, ferrovanadium dust	1
Iodine (I_2)	1
Nickel, metal and soluble compounds (except carbonyl, 0.007	1
Sulfuric acid	1
Tungsten, soluble compounds	1 (as W)
Zinc chloride fume	1
DDT	1
Asbestos (1% crystalline SiO_2)	2mppcf[c]
Tremolite (" " ")	5mppcf[c]
Graphite (natural)	5mppcf[c]
Toxic	
Asphalt (petroleum) fume	2
Hydrogen fluoride (HF)	2
Sodium hydroxide	2
Tin compounds (except organic compounds, 0.1; SnO_2, 15 and SnH_4)	2
Fluoride salts	2.5 (as F)
Chlorine (Cl_2)	3
Carbon black	3.5
Coal dust (bituminous)	3.5 (respirable)
Calcium oxide	5
Cyanides	5 (as CN)
Fibrous glass (5-7 diam.)	5
Formaldehyde	5
Manganese	6
Molybdenum, soluble compounds	5
Nitric acid	5
Oil mist, particulate	5
Tungsten, insoluble compounds	5 (as W)
Zinc oxide, fume	5
Hydrogen chloride	7
Nitrogen dioxide	9
Hydrogen bromide	10
Iron oxide fume	10
Methyl mercaptan	10
Wood dust, total dust	10
Sulfur dioxide	13
Hydrogen sulfide	15
Amorphous silica (incl. diatomaceous earth)	20mppcf[c]
Mica, soapstone, and talc	20mppcf[c]
Mild or Low Toxicity	
Boron oxide	15
Magnesium oxide fume	15
Molybdenum, insoluble compounds	15
Ammonia	35
Carbon monoxide	55
Carbon tetrachloride	65
Benzene	80
Methyl alcohol	260
Perchloroethylene	670
Liquefied petroleum gas	1800
"Inert" or Nuisance Particulates (<1% SiO_2)	15 (or 50 mppcf[c])
Aluminum oxide	
Calcium carbonate	
Cellulose	
Cement, portland	
Emery	
Glycerine mist	
Graphite, synthetic	
Limestone	
Magnesite	
Marble	
Plaster of Paris	
Rouge	
Silicon carbide	
Starch	
Sucrose	
Tin oxide	
Titanium dioxide	
Vegetable oil mists (except castor, cashew nut or similar irritant oils)	

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[a] Source: Reference 15.

[b] See Reference 15 for method of calculation.

[c] Million particles per cubic foot of air (mppcf x 35.3 = particles per cm^3). See Reference 15 for method of counting.

thousands of organic compounds which may be present as minor pollutants locally or even nationally.) These entries have, in general, been grouped according to increasing order of toxicity. One notes, however, that the so-called inert particulates have a lower TLV than such known poisons as carbon monoxide, demonstrating again that the physical properties of the inhaled substance are extremely important (i.e., a particulate which may be permanently retained vs. a gaseous compound which may be later exhaled, reversibly). The effect of particle size on toxicity has been studied rather extensively with a few substances such as silica, the silicates and natural graphite. TLV's have been set for these substances on the basis of particle count as shown also in Table 6.5-1.

One approach to rating the objectionability of air pollutants on the basis of toxicity is by use of the measured levels already present and consideration of these levels in relation to the TLV's. Mean and maximum concentrations have been measured for a number of air pollutants as already shown in Table 6.4-3. We have calculated the simple ratios of these values to the pertinent TLV's and ranked the pollutants on the basis of this ratio, which we have termed a "hazard factor." The results given in Table 6.5-2 indicate that mercury and lead are the two most serious metallic air pollutants. In fact, mercury levels as high as 28% of the TLV for industrial exposure have been measured in the ambient air.

Finally, a combination of the pollution factor (a measure of how far pollutant levels are above background, Table 6.4-4) with the hazard factor (a measure of the hazard presented by observed levels of toxic pollutants, Table 6.5-2) would appear to be a further useful basis for ranking pollutants (since one might assume that man can tolerate the normal background levels). The product of the pollution factor and the hazard factor, which we havé termed a "toxic hazard index", has been calculated for a number of pollutants. The pollutants are ranked on this basis as shown in Table 6.5-3.

6.6 Ranking by Effects on Materials and Facilities

Air pollutants emitted to the air can have a wide range of effects on materials, varying from the deposition of a dust covering to the complete dissolution by corrosion of the affected material. Dustfall values of 0.35 to 3.5 mg/cm^2/mo (10 to 100 tons/mile^2/mo) are typical of many cities and values as high as 70 mg/cm^2/mo (2,000 tons/mile^2/mo) have been recorded near sources of high emission (a dustfall of 10 mg/cm^2/mo would be a depth of about 0.1 mm/yr or 1 cm/century). Severe local problems can be incurred by the settling of larger particles (10-500 μ) of certain chemical compositions: acids or solvents which cause corrosion; iron-containing dust which causes rusting; gritty materials which may be abrasive; and organic materials which may be sticky, cohesive or sludge-forming. The suspended particulate ($< 10\ \mu$)

TABLE 6.5-2

HAZARD FACTOR RANKING OF TOXIC POLLUTANTS IN THE AIR

	Mean Basis		Max Basis	
Ranking	Pollutant	Hazard Factor[a] $([\text{Mean}]/\text{TLV})\times10^3$	Pollutant	Hazard Factor[a] $([\text{Max}]/\text{TLV})\times10^3$
	Metals		**Metals**	
1	Pb	4.0[b]	Hg	280.0[b]
2	Hg	2.0	Pb	43.0
3	Fe	0.31	Zn	11.6
4	Be ($\leq$ 4)	$<$ 0.25	Cu	10.0
5	V	0.17	V	7.3
6	Cd	0.13	Be	5.0
7	Zn	0.13	As	4.8
8	Cu	0.09	Fe	4.4
9	As	0.04	Cd	2.8
10	Ni	0.034	Mn	2.0
11	Cr	0.03	Cr	0.66
12	Mn	0.02	Co	0.6
13	Co	$<$ 0.005	Ni	0.46
14	Sn	0.004	Sb	0.33
15	Ti	0.004	Bi	0.13
16	Sb	0.002	Ti	0.11
17	Bi	$<$ 0.001	Sn	0.10
18	Mo	$<$ 0.0005	Mo	0.078
	Inorganic Salts			
	$SO_4^{=}$	0.7		
	NO_3^-	0.17		
	P (all forms)	0.07		
	NH_4^+	0.05		
	Organics			
	Benzene-soluble	0.7		
	Benzo(α) pyrene	3.0		
	Gaseous Pollutants[c]			
	CO	127.0		
	Oxidants (incl. O_3)	100.0		
	NO_2	15.7		
	HCl	10.0		
	SO_2	4.8		
	HF	4.0		
	NH_3	2.3		
	Hydrocarbons (excl. CH_4)	1.5		
	H_2S	0.3		

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[a] Mean and Max concentrations in μg/m^3 from Table 6.4-3. TLV's in mg/m^3 from Table 6.5-1 except: Bi (0.5 est.); Cd (0.15 avg.); Mo (10.0 avg.); Cr (0.5 avg.); Ti (10 est.); V (0.3 avg.); Fe (5 avg.); Sn (5 avg.). Benzene-soluble organic particulates (10 est.); benzo(α)pyrene (0.001 est.); and inorg. salts (est. 15 each). The 10^3 factor is used to give a convenient scale.

[b] Concentrations giving ratios of 4 and 280 represent 0.4% and 28%, respectively, of the TLV.

[c] Gaseous pollutants probably should not be compared directly to particulates, e.g., CO can be reversibly exhaled.

TABLE 6.5-3

TOXIC HAZARD INDEX OF AIR POLLUTANTS

Pollutant	Hazard Index*
Lead	3100
Carbon Monoxide	890
Mercury	400
Benzo(α)pyrene	78
Sulfur Dioxide	58
Ammonia	18
Sulfates	14
Zinc	8.7
Vanadium	8.5
Benzene-Soluble Organics	4.9
Cadmium	2.6
Iron	2.5
Nitrates	1.7
Beryllium	< 1.2
Nickel	1.1
Copper	0.8
Chromium	0.5
Ammonium Salts	0.4
Manganese	0.2
Arsenic	0.2
Antimony	0.02
Titanium	0.02
Cobalt	< 0.02
Bismuth	< 0.01
Molybdenum	< 0.01

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* Hazard Index = Pollution Factor x Hazard Factor (Both Mean Basis) Pollution Factors from Table 6.4-4 and Hazard Factors from Table 6.5-2. Units are μg/mg, i.e., 10^{-3}. See Table 6.5-2.

emissions and gaseous emissions which react in the atmosphere to form particulate may settle out or be adsorbed on materials at greater distances from the source and cause soiling, corrosion, electrical shorts (during conditions of high humidity), etc. The suspended particulate levels in urban atmospheres ranged from 60 $\mu g\ m^{-3}$ to about 200 $\mu g\ m^{-3}$ (annual geometrical mean), but 24 hr. average maxima were about three times the annual mean. For rural, non-urban areas the annual mean is 20-60 $\mu g\ m^{-3}$. Gruber and Schumann[16] have described a "soiling potential" of sources which quantifies the smoke emission from a source, in terms analogous to the "soiling index" of the atmosphere, which is a measure of the submicron, non-settling particles present.

Some economic costs of the effects of pollutants on materials have been estimated in a recent report.[17] In making these estimates two major damaging effects on materials were considered: soiling and deterioration. Fifty-three major materials were identified, the total value of each was estimated on the basis of the in-place (or final product) cost, and estimates were made of the economic cost or loss caused by air pollution in the United States.

In the estimation of costs due to soiling, the assumption was made that an increase in suspended particulate pollutant levels causes a directly proportional increase in soiling rate of materials, which is, in turn, reflected in either an increased cleaning cost or an equivalent loss in esthetic value. In other words, the basis of estimation was the added cost required to keep materials (i.e., those which we desire to have cleaned) as clean in a polluted area as people normally keep their homes in a nonpulluted environment. The results of these estimates, condensed in Table 6.6-1 indicate that 44 of the materials incurred losses totaling $100 billion. This value is obviously much greater than we are actually spending, although estimates of the actual value range as high as $30 billion. The difference is a measure of the esthetic cost of living in a dirty environment.

For deterioration, the economic loss caused by decreased lifetimes or impaired servicability (due to corrosion, discoloration, etc., produced by the pollutants) was used as the basis of estimation. The loss caused by deterioration, etc., was primarily based on gaseous, i.e., nonparticulate pollutants, but is included here for comparison. Unfortunately, the economic-cost factor could not be related by this method to a particular pollutant, because of a lack of available data on specific pollutants, but estimates of relative interactions were made for some specific material-pollutant combinations.* The results of these estimates, condensed in Table 6.6-2 indicate a loss of $3.8 billion for these materials, although the total cost of all deterioration losses may run as high as $9.5 billion according to the report.

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* Such as: stainless steel by particulates, Fe and Cl; cotton fabric by SO_2 and O_3; and paint by H_2S, SO_2, Fe, and Cu and particulates.

TABLE 6.6-1

SOILING

Rank	Material	Soiling Cost (Billion $)
1	Paint	35.0
2	Zinc	24.0
3	Flat glass	19.0
4	Cement and concrete	5.4
5	Aluminum	4.9
6	Leather	2.5
7	Polystyrene (plastic)	2.2
8	PVC (plastic)	1.54
9	Paper	1.12
10	Nickel	1.00
11	Polyethylene (plastic)	0.59
12	Cotton (fiber)	0.34
13	Copper	0.19
14	Brass and bronze	0.17
15	Chromium	0.16
16	Stainless steel	0.14
17	Building brick	0.11
18	Polypropylene (plastic)	0.090
19	ABS (plastic)	0.085
20	Synthetic rubber	0.070
21	Building stone	0.069
22	Lead	0.065
23	Urea and melamine (plastic)	0.061
24	Wool	0.055
25	Tin	0.053
26	Cellulose ester (fiber)	0.044
27	Polyesters (plastic)	0.041
28	Phenolics	0.040
29	Rayon (fiber)	0.033
30	Nylon (plastic)	0.029
31	Bituminous materials	0.027
32	Acrylics (plastic)	0.026
33	Wood	0.025
34	Acetate (fiber)	0.015
35	Nylon (fiber)	0.014
36	Epoxies (plastic)	0.011
37	Cellulosics (plastic)	0.010
38	Acrylics (fiber)	0.005
39	Polyesters (fiber)	0.003
40	Magnesium	0.002
41	Acetate (plastic)	0.001
42	Polyolefin (fiber)	0.001
43	Gold	< 0.001
44	Silver	< 0.001
45	Gray iron	No loss
46	Malleable iron	"
47	Alloy steel	"
48	Molybdenum	"
49	Clay pipe	"
50	Refractory ceramics	"
51	Carbon and graphite	"
52	Natural rubber	"
53	Carbon steel	"
TOTAL		100

TABLE 6.6-2

DETERIORATION

Rank	Materials	Value Economic Loss (Million $)
1	Paint	1,195.0
2	Zinc	778.0
3	Cement and concrete materials	316.0
4	Nickel	260.0
5	Cotton (fiber)	152.0
6	Tin	144.0
7	Synthetic rubber	140.0
8	Aluminum	114.0
9	Copper	110.0
10	Wool (fiber)	99.2
11	Natural rubber	54.0
12	Carbon steel	53.8
13	Nylon (fiber)	38.0
14	Cellulose ester (fiber)	32.8
15	Building brick	24.2
16	Urea and melamine (plastic)	22.7
17	Paper	22.6
18	Leather	20.6
19	Phenolics (plastic)	19.8
20	Wood	17.6
21	Building stone	17.6
22	PVC (plastic)	15.4
23	Brass and bronze	13.9
24	Polyesters (plastic)	13.7
25	Rayon (fiber)	13.2
26	Magnesium	13.0
27	Polyethylene (plastic)	11.7
28	Acrylics (plastic)	10.0
29	Alloy steel	8.7
30	Polystyrene (plastic)	8.5
31	Acrylics (fiber)	7.6
32	Acetate (fiber)	7.6
33	Polyesters (fiber)	6.4
34	Polypropylene (plastic)	6.4
35	ABS (plastic)	6.1
36	Epoxies (plastic)	4.7
37	Cellulosics (plastics)	4.0
38	Bituminous materials	2.2
39	Gray iron	1.9
40	Nylon (plastic)	1.7
41	Polyolefins (fiber)	1.6
42	Stainless steel	1.6
43	Clay pipe	1.4
44	Acetate (plastic)	1.2
45	Malleable iron	0.9
46	Chromium	0.8
47	Silver	0.7
48	Gold	0.6
49	Flat glass	0.3
50	Lead	0.2
51	Molybdenum	0.1
52	Refractory ceramics	0.02
53	Carbon and graphite	0.00
TOTAL		3,800

6.7 Ranking of Pollutants on the Basis of Overall Objectionability

The "overall objectionability" of a pollutant should reflect some kind of a weighted average of its different objectionable properties. A ranking on this basis is extremely difficult to achieve because of the diverse characters of the pollutants and the wide variations in their effects on different receptors. We have, nevertheless, attempted this type of ranking by employing the notion of an air quality goal, AQG. The AQG's, as used herein, should not be confused with the Air Quality Standards which are being set by authoritative bodies. Unfortunately, a complete set of Standards is not yet available and we have, therefore, developed a set of AQG's. These assigned AQG's are based upon several considerations including toxicity to man, animal and plant life, corrosion and soiling of materials, odor, reduction of visibility, and formation of haze (particularly a colored haze). The numerical values, in $\mu g \cdot m^{-3}$, are assigned as the upper concentration limits which we want to occur at any ground level point, either in the air basin affected by the source or downwind from a source.

Because effects such as toxicity to plant or animal life have an extremely complex relationship to concentration and exposure times, an effort was made in these assignments to include a factor which would reflect normal atmospheric fluctuations. Since atmospheric inversions frequently last up to one day and periods of stagnation may last from three to seven days we have selected a time-averaging period of 1-5 days as a basis of selecting the AQG's, i.e., the pollutant level may, without being seriously objectionable, build up occasionally, but periodically, to the AQG followed by meteorological ventilation within 1-5 days.

A number of pollutants have been assigned AQG's and ranked on this basis as shown in Table 6.7-1. Many gaseous pollutants are included in order to indicate the range of the scale and for comparison. The inclusion of more specific types of particulate pollutants would have been desirable, but they would be believed generally to fall in the range 10-100 $\mu g \cdot m^{-3}$.

6.8 Ranking of Sources on the Basis of Overall Objectionability

6.8.1 Objectionability Rating of Industries

An objectionability rating of sources by industrial classification is extremely difficult because of the large ranges in the factors which affect the quantity and type of particulate emitted by a given type of source and the lack of data on the chemical composition and physical properties of emitted pollutants. In Table 6.8-1 we have rated on a relative scale various major particulate sources on the basis of their contribution to the overall problems of soiling, corrosion, toxicity, and odor as arising from air

TABLE 6.7-1

RANKING OF AIR POLLUTANTS BY AIR QUALITY GOALS

Air Pollutant	Relative Ranking*	Basis of Ranking
Carcinogens	0.001	toxicity
Beryllium, Mercury	0.1	toxicity
Highly toxic metals (Cd, Cr, Pb, Se, V, etc.)	1	toxicity
Mercaptans	5	odor and toxicity
Isocyanates	5	toxicity
Asbestos, silica, silicates	5	toxicity
Very toxic metals (As, Sb, Cu, Ni, W)	5	toxicity
Fluorides, as HF	10	vegetation damage
Alkyl amines	20	odor, toxicity
Hydrogen sulfide	30	toxicity, corrosion (paint), (odor?)
Calcium oxide and other alkalis	30	toxicity
Mineral acids (HCl, HNO_3, H_2SO_4, H_3PO_4)	50	toxicity, corrosivity, soiling
Sulfates, nitrates, fluorides (as salts)	50	toxicity, vegetation damage, electrical conductivity
Sulfur oxides	50	toxicity, vegetation damage
Organo sulfides and pyridines	50	odor and toxicity
Nitrogen oxides	50	toxicity, color, atm. rxns.
Chlorine	50	toxicity, corrosivity, (odor?)
Soot, smoke, carbon black	50	soiling, toxicity
Less toxic metals (Fe, Mn, Mo, Ti, Zn, etc.)	50	soiling, toxicity
Fly ash (from coal combustion)	75	soiling, toxicity
Inert particulates	100	soiling, visibility
Oxidants (ozone, etc.) total	100	corrosion, toxicity
Olefins, aldehydes, phenols, aniline	100	toxicity, soiling, corrosion
Aromatics, chlorocarbons, mixed organics	200	toxicity, soiling
Ammonia	500	toxicity, atm. rxns., (odor?)
Hydrocarbons (exclusing CH_4)	500	soiling, toxicity, atm. rxns.
Carbon monoxide	3,500	toxicity

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* Ranked in order of decreasing objectionability; i.e., a low number indicates a highly objectionable pollutant. Numerical values were chosen to correspond with maximum tolerable level in $\mu g/m^3$ during occasional 1-5 day pollution episodes.

TABLE 6.8-1

RANKING OF AIR POLLUTION SOURCES ON THE BASIS OF OVERALL OBJECTIONABILITY

Sources*	Soiling	Corrosivity	Odor	Toxicity
Electric Utilities				
Coal-fired	C	C	C	C
Oil-fired	B	B	A	B
Gas-fired	A	A	-	-
Heating Plants				
Coal	C	C	C	C
Oil	C	C	A	B
Gas	A	A	-	-
Wood, etc.	C	B	A	C
Incinerators				
Industrial	C	B	A	B
Commercial	C	B	A	B
Municipal	C	B	A	B
Residential & Apartment	C	B	A	B
Mining and Quarrying				
Iron	C	B	-	A
Copper	C	A	-	A
Lead	C	A	-	B
Zinc	C	A	-	A
Aluminum	C	A	-	A
Nonmetals	C	A	A	A
Ferrous Metals				
Taconite handling	C	C	-	A
Steel furnaces	C	C	A	C
Foundries	C	C	A	C
Finished products	B	A	-	A
Nonferrous Metals				
Aluminum	C	C	A	C
Copper	C	B	C	B
Lead	C	B	C	C
Zinc and brass	C	B	C	B
Minor Metals and Metalloids (Production and Use)				
Arsenic	A	A	-	B
Beryllium	A	A	-	B
Cadmium	A	A	-	C
Cobalt	A	A	-	A
Chromium	A	A	-	C
Phosphorus	A	A	-	A
Manganese	A	A	-	B
Mercury	A	A	-	C
Molybdenum	A	A	-	B
Tin	A	A	-	A
Titanium	A	A	-	A
Vanadium	A	A	-	C
Food Products				
Meat processing	B	A	C	B
Grain and grain products	C	-	C	C
Food Products (Concluded)				
Sugar, candy, and confections	A	-	A	-
Coffee	B	-	B	B
Fats and oils	B	A	A	A
Textile Products				
Mills	B	B	A	B
Forest Products				
Wood	C	A	A	-
Pulp and paper	C	B	C	B
Chemicals				
Ammonia	A	B	A	A
Chlor-alkali	A	B	A	B
Mineral acids	B	C	B	C
Pigments	C	B	A	A
Coal tar products	B	B	B	C
Carbon black	C	A	-	A
Soap and detergent	C	B	B	A
Plastics and resins	C	C	B	C
Synthetic fibers	C	C	B	C
Synthetic rubber	C	B	B	B
Agricultural chemicals	C	B	C	C
Fertilizers	C	C	B	C
Paints and varnish, etc.	C	C	C	C
Polishes	A	A	A	A
Toilet and sanitation goods	A	A	A	A
Inks	B	A	A	A
Glue and gelatin	B	A	A	A
Explosives	A	A	A	A
Petroleum Refining and Related Industries	C	C	C	C
Rubber Goods	C	A	A	A
Leather Products	A	A	A	A
Glass Products	C	B	A	C
Stone and Clay Products				
Asbestos products	C	A	-	C
Abrasives	A	A	A	A
Brick and tile	C	A	-	A
Ceramics	B	A	A	B
Perlite, rock wool	B	A	A	B
Gypsum products	C	B	A	B
Crushed stone	C	A	-	A
Cement Production	C	B	A	B
Lime Production	C	B	A	B
Asphalt				
Batching	C	A	B	C
Roofing	C	A	C	B

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* Ranking System
C = Serious and/or frequent problem
B = Significant local problem
A = Occasional problem
Dash (-) indicates little or no problem

Ranked on the basis of existing conditions in the United States of population distribution, controls used, etc.

pollution. In making rankings we have tried to take into consideration the number, distribution and proximity to materials of the sources, the nature and tonnage of pollutants emitted by a typical source, and the total tonnage emitted throughout the country. This estimate then includes the average control in use.

Considerable subjectivity is inherent in this method of ranking. We have, however, relied on the general literature and other work on this program as indicated below.

6.8.1.1 Soiling and corrosion: In Tables 6.6-1 and 6.6-2, we reported estimates which have been made on the economic costs arising from soiling and deterioration of materials caused by pollution and in Table 4.1-1 we have listed total tonnages of particulates emitted. Soiling is in general proportional to total tonnage with special consideration given to sooty or smoky emissions. The corrosivity reflects the effect of gaseous pollutants such as SO_2, O_3, H_2S, or NH_3 which are either corrosive in themselves or react in the atmosphere to form corrosive acids or salts which increase corrosion. It also reflects the emission of pollutants such as Fe or Cu which cause paint discoloration, rust coloration, etc., or increase corrosion of certain materials.

6.8.1.2 Odor: In Tables 6.3-1 and 6.3-2, we noted that malodors are the cause of a high percentage of complaints concerning air pollution. Some further information of this type (from other sources) is reported in Table 6.3-3 in which the sources are ranked on the basis of complaints received.

6.8.1.3 Toxicity: In Table 6.5-1 we listed the relative toxicities of various potential pollutants and in Tables 6.5-2 and 6.5-3 ranked a number of pollutants by the "hazard factor" and "hazard index" which they present at observed levels in urban atmospheres. In addition to those materials, such pollutants as polyaromatic hydrocarbons (frequently carcinogenic) and volatile compounds such as SO_2 have been considered in the rankings in Table 6.8-1. We reemphasize that the degree of control is considered in these rankings.

6.8.2 Objectionability Rating of Individual Sources

A system which would objectively rate an air pollution source in terms of its emission strength and the "objectionability" of its pollutants would be extremely useful. In 1962 Calvert[18/] proposed an air pollution rating index system in which a "source index" (a measure of the seriousness of the pollution source) was compared to a "location index" (a measure of the ability of the atmosphere to dilute the pollutants). By using this approach one could determine (using certain approximations) if the pollutants (gaseous or particulates of < 20 μ diameter) would be sufficiently diluted between a specified source and a downwind receptor, so that the concentrations were below desired limits. Calvert has suggested[19/] modifications to the original index system which have been incorporated and extended herein.

In the original index system[18/] the approach was essentially local in that the atmospheric diffusion equations (of Bosanquet and Pearson) were used to calculate the maximum concentration at any point downwind of a source - a smokestack of given effective height. Unfortunately individual variations in topography, local weather patterns, stack heights, plume density, distance to the receptor, the presence of nearby pollution sources, etc. tend to limit the use of the generalized form of the index. In the present work, a more regional approach is taken with dispersion estimates based on the NAPCA workbook method.[20/] The initial assumptions are simple as follows:

An emission source of strength Q($g\ sec^{-1}$) is essentially continuous (i.e., emission time is long compared to the travel time downwind). Atmospheric conditions are taken as conducive to some buildup of pollutants but not as an extremely stable system. A typical example might be Type C Stability with a wind of 2 $m\ sec^{-1}$ (4.5 mph). At a distance of about 10 km (6.21 miles) downwind, the ground level concentration,* χ($\mu g\ m^{-3}$) of the pollutant from this source is dependent primarily on the mixing depth of the atmosphere and is essentially independent of the stack height or effective stack height, as shown by the graphs[20/] of $\frac{\chi u}{Q}$ vs. distance (where u is the wind velocity in $m\ sec^{-1}$). Thus, for Type C stability** and a mixing depth of 500 m the value of $\frac{\chi u}{Q}$ is about $10^{-6}\ m^{-2}$, or $\chi = \frac{Q}{2} \times 10^{-6}\ g\ m^{-3} = \frac{Q}{2}\ \mu g\ m^{-3}$ (the concentration at 10 km is much less sensitive to changes of distance than at say 1 km and is much less sensitive to other local variations).

The index is now calculated at the ratio of the regional concentration of pollutant from this source to an accepted standard. Unfortunately, authoritative bodies have not yet agreed on standards for many pollutants. However, the Air Quality Goals (AQG) as defined on page 266 and listed in Table 6.7-1 are well suited for use as standards in calculating the pollution index. Taking the AQG in $\mu g\ m^{-3}$, the regional pollution index, I_R, is given by:

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* This concentration is less than the maximum, produced by a given effective stack height, e.g., 100 m. The maximum would usually occur at a point nearer to the stack.

**For type A or B stability the mixing depth is slightly less at this value of $\frac{\chi u}{Q}$, while with types D and E stability the value of $\frac{\chi u}{Q}$ drops to about 10^{-5} at a mixing depth of 100 m at 10 km.

$$I_R = \frac{\chi}{AQG} = \frac{Q}{2(AQG)} \qquad \text{(Eq. 1)}$$

The degree to which a particular source contributes to the overall pollution problem for a given pollutant is also of interest. The total regional index for a pollutant could be taken as the ratio of the concentration from the source of interest, χ_1 plus that from all other sources, β, to the AQG:

$$I_R(T) = \frac{\chi_1 + \beta}{AQG} \qquad \text{(Eq. 2)}$$

where β includes the natural background plus the concentrations arising from other man-made sources: $\beta = B + X_2 + X_3 + \cdots$. β may be simply replaced by B for many applications. The objectionability index, I_{Ob} of the source of interest is then a measure of this source's contribution to the overall problem and is calculated as:

$$I_{Ob} = \frac{I_R}{I_R(T)} = \frac{\chi_1}{\chi_1 + \beta} \qquad \text{(Eq. 3)}$$

or

$$= \frac{1/2\ Q_1}{1/2\ Q_1 + \beta} = \frac{Q_1}{Q_1 + 2\beta} \qquad \text{(Eq. 4)}$$

The objectionability index (unlike the pollution index) will always be between zero and unity (a high value being unfavorable). Since it is completely independent of the AQG it loses some of the sensitivity of the pollution index and the two should be used together to rate a source. (Note that the constant 2 in Eq. 4 has the units 10^6 m^3 sec^{-1}.)

The following examples illustrate the potential usefulness of the index system in the comparison of various sources and degrees of control.

Example: A source of strength 100 g sec^{-1} of "inert" particulates (which have an assigned AQG of 100 $\mu g\ m^{-3}$) would have an index $I_R = 0.5$ and I_{Ob} of 0.56 (assuming a background of 40 $\mu g\ m^{-3}$). Similarly a source of only 0.05 g sec^{-1} (10 lb/day) mercury (which has a AQG of 0.1 $\mu g\ m^{-3}$ and a background of 0.005 $\mu g\ m^{-3}$) would have $I_R = 0.25$, an I_{Ob} of 0.98, and would be as objectionable as the 100 g sec^{-1} of the "inert" particulates. In contrast a source of 10 g sec^{-1} of ammonia (AQG - 500) would have $I_R = 0.01$ and would be nonobjectionable.* The data are summarized below.

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* (In fact, NH_3 would be undetectable, i.e. not above background, at 10 km distance.)

Pollutant	Q g sec^{-1}	I_R	I_{Ob}
Inert Particulate	100	0.5	0.56
Hg	0.05	0.25	0.98
NH_3	10	0.01	0.33

Example: The assumption of a "unit plant" has been shown[21/] to be a useful criteria for comparing industrial pollution sources. Similarly, the assumption of a typical plant size and emission factor can be used to obtain values for typical source strengths, in the absence of actual emission data for a truly representative plant. Thus assume that an electric power plant uses 200,000 ton/yr pulverized coal. Using an emission factor for particulate of 190 lb/ton, and AQG of 75 µg/m^3 and a background level of 40 µg/m^3, the regional pollution index and objectionability index can be calculated at various degrees of control as shown below:

% Control	Q (g sec^{-1})	I_R	I_{Ob}	Remark
0	540	3.6	0.87	extremely objectionable
80	108	0.7	0.57	objectionable
97	16	0.1	0.16	unobjectionable

A comparison of the objectionability of the SO_2 emissions with that of the particulates is also of interest. Assuming 90% of the sulfur in the coal is emitted as SO_2, that the AQG for SO_2 is 50 µg/m^3, and the natural background is 5 µg/m^3, the indices at two levels of sulfur would be:

% Sulfur	Q(g sec^{-1})	I_R	I_{Ob}	Remark
4	415	4.2	0.98	very objectionable
0.5	52	0.5	0.89	probably objectionable

The relatively high values for the low sulfur coal compared to the controlled particulate values are at first surprising. In part they reflect the low value for the AQG and the use of the natural background. Even if the urban average of 62 µg/m^3 SO_2 and a total background of, say, 35 µg/m^3 are used, then $I_R = 0.4$ and $I_{Ob} = 0.43$, and the SO_2 is still shown to be more objectionable than the particulate at 97% control.

The availability of data on the source strengths unfortunately limits the extent to which the rating system can be applied at present. In the first place a great range of strengths exists within a given type of source because of plant size, method of operation, type of fuel used (and in the case of coal, the type of boiler and ash content), type of control equipment and its operating efficiency, etc. In addition, in many cases the chemical compositions of the emitted particulates have not yet been determined so that the most objectionable constituents of the emissions can be identified and employed in the calculations. In other cases the particle size distribution may not be known so that the large, settleable particles can be excluded from the calculations. The collection of these data is beyond the scope of the present program. As more and better data become available, however, and agreement is reached by authoritative bodies on the air quality standards to be used, the index system should be applied to every source.

6.9 Conclusions

Attempts have been made using several methods to rank particulate air pollutants and their sources on the basis of objectionable properties. Particulate pollutants which produce readily apparent soiling (such as dust, soot and smoke) are the primary cause of complaints which are received from the public by air pollution control agencies. Complaints about odorous pollutants (usually gaseous) are generally the second most numerous, while other complaints arise from property damage (to paint, vegetation, livestock, etc.) and nuisance effects. Four categories of particulate sources which cause the most complaints appear to be: (1) the primary metals industries; (2) the stone, clay and glass products industries; (3) petroleum and related industries; and (4) refuse disposal. The largest single source of complaints are asphalt plants.

If levels of specific particulate pollutants are compared on the basis of their "pollution factors," i.e., their observed increase above "natural" background levels, then lead and mercury are by far the most serious air pollutants in our cities. Levels of other pollutants which average far above background include carbon monoxide, zinc, vanadium, nickel, benzo-(α)pyrene, cadmium, sulfates and sulfur dioxide. Maximum levels of over 1000 times background have been observed for many pollutants, including an observation of 28,000 times background for mercury in the air in one instance.

If the observed average levels of specific pollutants are compared with their relative toxicities, then again lead and mercury have the highest "hazard factor" among metallic air pollutants. Carbon monoxide, oxidants, nitrogen oxides, hydrogen chloride, hydrogen fluoride and benzo(α)pyrene. are also serious toxicants in the air on this basis. In one instance, a mercury level of 28% of the threshold limit value for industrial exposure was measured in the ambient air of one of our cities. When the pollution factors and hazard factors were combined, (i.e., to consider the average observed pollutant levels, the normal background levels, and the relative toxicities) then the resulting "hazard index" showed the most serious air pollutants to be in decreasing order: lead, carbon monoxide, mercury, benzo(α)pyrene and sulfur dioxide.

On the basis of effects on materials, soiling by particulates is the major problem and has been estimated to be the cause of $100 billion of real and esthetic damage in the United States. Corrosion of materials has been estimated as the cause of another $3.8-9.5 billion damage by air pollutants, although in this case much of the damage is caused by pollutants which are emitted as gases.

On the basis of overall objectionability, the highly toxic pollutants such as carcinogens, mercury, beryllium, isocyanates, lead, asbestos, etc., are ranked as much more serious pollutants than those which cause soiling, property damage, etc.

A subjective ranking of industrial sources on their overall objectionability was also made, in the categories of soiling, corrosivity, odor and toxicity of their emissions. As guides in this ranking, an effort was made to take into account the nature and tonnage of pollutants emitted by typical examples of each industry and the total for that industry, as well as the distribution of the industry in relation to population centers. On this basis the most serious sources appear to be the coal-fired electric utilities and industrial heating plants, and the petroleum-related industries. An objective method for the overall rating of sources of diverse objectionable pollutants is described. This method employs a regional pollution index, which compares the concentration of a pollutant which results from a given emission level to an allowable maximum concentration or standard, and also an objectionability index which compares the concentration of a pollutant from a given source with that of all sources, including natural background levels.

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7. MISCELLANEOUS RANKING TECHNIQUES

There are many ways of arranging the information we have collected on stationary particulate pollutant sources which will lead to useful presentations. In this section, a preliminary development of two such arrangements is presented. These are Difficulty of Control and Unit Operation.

7.1 Difficulty of Control

To discuss particulate pollution sources in terms of difficulty of control, it is necessary to select a set of guidelines to judge the degree of difficulty. These guidelines should include effluent characteristics and process variables. A review of possible guiding factors indicated that the most significant ones are: (1) particle size distribution of emitted particulates; (2) grain loading; (3) carrier-gas volumetric flowrate; (4) particulate and carrier-gas handling characteristics (i.e., corrosive, sticky, etc.); (5) number of small sources (i.e., transfer points); and (6) nature of process.

A division of stationary particulate pollution sources into the broad categories of metallurgical, chemical, combustion, and mechanical processes also facilitates a ranking of difficult sources. Metallurgical processes contain some of the most difficult sources to control because effluent streams are characterized by metallic fumes and high volumetric flowrates. In many cases, the particulates are corrosive, sticky, and have high angles of repose. In addition to the high volumetric flowrates, the carrier-gases are at high temperatures and may be corrosive.

Particulates emitted from mechanical processes are generally not inherently difficult to control, but the number of sources may present a problem. Conveyor transfer points, loading and unloading operations, and stockpiles are examples of this type of source.

Table 7.1-1 presents a list of sources that are difficult to control in the metallurgical, chemical, combustion, and mechanical process categories. The factors that make the sources difficult to control are delineated. The ranking is not strictly quantitative. However, the metallurgical, chemical, and combustion processes are inherently more difficult to control than are mechanical processes.

TABLE 7.1-1

PARTICULATE POLLUTION SOURCES DIFFICULT TO CONTROL

Source	Problem
I. Metallurgical Processes	
A. Iron and Steel	
1. Sinter Machine	High temperature and high volumetric flowrate carrier-gas. SO_2 content. High particle electrical resistivity. Fluorides in effluent are corrosive.
2. Electric Furnace	Small particle size of particulate (70 wt% < 5 micron). Particulates have a strong tendency to adhere to fabric surfaces, high angle of repose and a high electrical resistivity.
3. Coke Ovens	Basic nature of charging and pushing steps.
B. Gray Iron Foundries	
1. Cupola	Small size of particulate (25-30 wt% < 10 micron). Variable gas-stream conditions. Fluxing agents may produce corrosive effluents.
2. Electric Furnace	Small size of particulate.

TABLE 7.1-1 (Continued)

Source	Problem
C. Primary Nonferrous	
1. Copper and Lead	
a) Blast, Reverberatory, and refining Furnaces	Small size of particulate (metallic fumes). Particulates are cohesive and will bridge and arch in hoppers.
2. Zinc	
a) Horizontal Retort	Small size of particulate (metallic fumes). High volumetric flowrate of carrier gas. Low outlet grain loading.
3. Aluminum	
a) Reduction Cells	Small particle size of particulate. High volumetric flowrate of carrier gas. Particulates may contain tar and fluorides. Particulates and carrier gas are corrosive.
b) Refining Furnaces	Small particle size of particulate. Particulate and carrier gas are corrosive.
D. Secondary Nonferrous	
1. Furnaces	Small particle size of particulate. Particulates may be abrasive or corrosive. Particulates may have high electrical resistivity. High temperature carrier gas.

TABLE 7.1-1 (Continued)

Source	Problem
E. Ferroalloys	
1. Blast Furnace	Small particle size of particulate (80 wt% < 1 micron). High temperature and high volumetric flowrate carrier gas. Carrier gas is potentially explosive because of high CO content.
2. Electric Furnace	Small particle size of particulate. Particulates have high electrical resistivity.
II. Chemical Processes	
A. Acid Manufacture	
1. Sulfuric (Contact Process)	
a) Absorber	Small particle size of particulate (acid mist). Corrosive effluent.
2. Phosphoric (Thermal Process)	
a) Absorber	Small particle size of particulate (acid mist). Corrosive effluent.
B. Fertilizer Manufacture	
1. Dryers and Coolers	Small particle size of particulate (fluoride fumes).
2. Prill Towers	Nature of process.

TABLE 7.1-1 (Concluded)

Source	Problem
C. Pulp Mills	
1. Recovery Furnace	Small particle size of particulate (50 wt% < 1 micron). High volumetric flowrate.
D. Carbon Black	
1. Channel Process	Nature of process. Small size of particulate.
2. Furnace Process	Small size of particulate.
III. Combustion Sources	
A. Power Plants (Electric Utility and Industrial)	Small particle size of particulate from some furnaces.
B. Slash and Field Burning	Nature of process. Multiple sources.
C. Incineration	Multiple sources.
IV. Mechanical Processes	
A. Crushed Stone, Sand & Gravel	
1. Stockpiles	Nature of process.
2. Materials Handling	Multiple sources.
B. Grain Elevators	
1. Materials Handling	Multiple sources.

7.2 Ranking Particulate Sources by Unit Operation

Particulate emission sources can also be ranked by unit operation. A ranking on this basis delineates similarities and differences between emissions from a specific unit operation in different industries. The ranking could be developed in terms of tonnage of emitted particulate or appropriate effluent characteristics. Incomplete data on emission and production figures were found for many unit operations in specific industries, and a meaningful ranking on the basis of tonnage emitted could not be developed. As a consequence, a ranking of classification using effluent characteristics was sought.

Table 7.2-1 presents a listing of particulate sources by unit operations and selected effluent characteristics. The effluent characteristics are: (1) particle size of emitted particulate; (2) outlet grain loading; and (3) carrier-gas flowrate. Particle size data are presented as mass median (in microns) and geometric deviation (σ) where available or as weight percent less than a specific diameter (microns). Outlet grain loadings are in grains per standard cubic foot. Quantities with an asterik are in actual cubic feet. Carrier-gas flowrate is expressed in two forms: (1) thousands of standard cubic feet per minute, and (2) thousands of standard cubic feet per ton processed. Quantities with an asterik are in actual cubic feet.

The unit operations listed in Table 7.2-2 are: (1) kilns; (2) dryers; (3) sinter machines; (4) roasters, (5) furnaces; (6) crushing, grinding, and milling; and (7) miscellaneous chemical processes. These unit operations account for a major portion of particulates emitted from stationary sources.

TABLE 7.2-1

PARTICULATE SOURCES BY UNIT OPERATIONS AND SELECTED EFFLUENT CHARACTERISTICS

Unit Operations	Particle Size	Outlet Grain Loading	Carrier-gas Flowrate ‡	Control Equipment **
I. Kilns				
a) Cement				
1. Rotary	Mass Median-8.5 σ = 4.1	Dry Process 1 - 17* Wet Process 1 - 14*	Dry Process a) 34 - 300* b) 94 - 614* Wet Process a) 72 - 445* b) 166 - 570*	MC, EP, MC & FF MC & EP
2. Vertical		0.8*	a) 73.6*	MC, EP
b) Lime				
1. Rotary	Mass Median-44 σ = 13.7	2 - 23	a) b) 57 - 204*	MC, EP, FF, WS
2. Vertical	10 < 10, 50 < 30 (one kiln)	0.3 - 1.0	a) 33.5*	
c) Bauxite (Rotary)	25 - 40 < 10	2.2*	a) 29.5*	MC, EP
d) Magnesite (Rotary)	50 < 10 (one kiln)			MC, EP
e) Zinc Ore (Rotary)		5.7 - 17.3*	a) 4.7 - 7.4*	MC, EP
f) Nickel Ore (Rotary)		12	a) 26.5*	MC, EP

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‡ a) Thousands of SCFM
  b) Thousands of SCF/ton

TABLE 7.2-1 (Continued)

Unit Operation	Particle Size	Outlet Grain Loading	Carrier-gas Flowrate	Control Equipment
II. Dryers				
a) Rotary 1. Grain				
2. Cement	40 - 70 < 10	13-40	b) 26 - 64*	EP, MC, FF
3. Phosphate Rock		7.63		WS
4. Titanium Dioxide	0.5 - 1	1 - 5		WS
5. Ammonium Nitrate	Large, unstable Agglomerates			WS
6. Fertilizer (Superphosphate)	Mass Median-85 $\sigma = 6.3$	0.7 - 4.0	a) 16.5 (one unit)	WS
7. Asphalt Stone (Hot Mix Paving Plant)	Mass Median-17.8 $\sigma = 5.1$	20 - 70	a) 7.7 - 46 b) 3.9 - 24.6	MC, WS, FF
8. Bauxite		20 - 40	a) 11 - 150*	EP, MC
9. Fuller's Earth		1.9	a) 17.6*	EP
10. Limestone	Mass Median-7 $\sigma = 9.7$	4.3 - 11	a) 14.7*	MC, WS
11. Dolomite		6.1 - 30.4	b) 36 - 43*	MC, WS

TABLE 7.2-1 (Continued)

Unit Operation	Particle Size	Outlet Grain Loading	Carrier-gas Flowrate	Control Equipment
12. Clay			a) 23.8	MC
13. Coal			a) 20 - 135	MC
b) Spray 1. Detergent	50 < 40	3		MC
2. Fertilizer a) Urea				
III. Sinter Machines				
a) Iron Ore	Mass Median-100 $\sigma = 5.4$	0.2 - 5.0	a) 30 - 460 b) 148 - 230*	MC, EP
b) Lead Ore		0.87 - 6.6	a) 140 b) 130 (one plant)	WS, MC
c) Zinc Ore	100 < 10	0.44 - 5	b) 140	
IV. Roaster				
a) Copper Ore		6.6	a) 4.6 b) 47.3	MC, EP, WS
b) Zinc Ore 1. Ropp			a) 25 - 30	MC
2. Multiple Hearth			a) 5 - 6	MC
3. Suspension			a) 10 - 15	MC
4. Fluid-Bed			a) 6 - 10	MC

TABLE 7.2-1 (Continued)

Unit Operation	Particle Size	Outlet Grain Loading	Carrier-gas Flowrate	Control Equipment
c) Pyrites		0.5 - 1.0*	a) 6.5 - 7.7*	
V. Furnaces				
a) Blast				
1. Iron Ore	15 - 90 <74	4 - 30	a) 40 - 140* b) 60 - 138	MC, WS, EP
2. Lead	0.03 - 0.3	2 - 6.6	a) 6 - 190 b) 180	MC, WS, EP
3. Copper		6.6	a) 21.2 b) 76.5	
4. Secondary lead		2 - 12	a) 2.1	MC, WS
5. Ferro Manganese	80 < 1	4.5 - 17	a) 60* - 135	EP, SA, WS
6. Tin Ore		2.1 - 3.0*	a) 2.1 - 5.7*	MC, EP
7. Antimony Ore		1.6*	a) 3.7*	MC, EP
b) Open Hearth				
1. Steel (no oxygen lance)	50< 1	0.1 - 3.5	a) 25 - 100	WS, EP
2. Steel (oxygen lance)	69< 10	0.2 - 7.0	a) 45 - 200	WS, EP

TABLE 7.2-1 (Continued)

Unit Operation	Particle Size	Outlet Grain Loading	Carrier-gas Flowrate	Control Equipment
c) Basic Oxygen (Steel)	85 - 95 < 1	2 - 10	a) 35 - 250*	WS, EP
d) Electric-Arc				
1. Steel (no oxygen lance)	84 < 10	0.1 - 2.2	a) 10 - 100	WS, EP, FF
2. Steel (oxygen lance)		1 - 10		WS, EP, FF
3. Ferroalloy	0.01 - 4	0.2 - 30	a) 11 - 60	WS, FF, EP
4. Iron Foundry				
e) Reverberatory				
1. Copper		1 - 5	a) 25 - 60 b) 71	MC
2. Lead		0.4 - 4.4	a) 1 - 3 b) 3.5 - 17.5	MC
3. Brass	0.05 - 0.5	1 - 8	a) 5.6 - 17.6	WS, FF
4. Secondary lead	0.07 - 0.4	1 - 6	a) 3.1	WS, FF
5. Secondary zinc		0.2 - 1	a) 7 - 8 b) 400 - 800	WS, FF
6. Secondary Aluminum	31 < 10	0.12 - 0.6	a) 1 - 9 b) 0.1	FF

TABLE 7.2-1 (Continued)

Unit Operation	Particle Size	Outlet Grain Loading	Carrier-gas Flowrate	Control Equipment
VI. Crushing and Milling				
a) Crushing Ore	0.5 - 100	5 - 25		WS
b) Cement Mill		22.3	a) 14.1*	EP
c) Limestone Crusher		1.1 - 1.3	a) 18.2	
d) Raymond Mill (Limestone)	Mass Median-4.3 σ = 1.6			
e) Hammer Mill (Limestone)	Mass Median-6.0 σ = 8.8			
f) Pulverizer (Hydrated Lime)	Mass Median-4.9 σ = 2.1			
g) Jaw Crusher (Stone)				
VII. Miscellaneous Chemical				
a) Absorption Towers				
1. Sulfuric Acid (Contact Plant)	8 - 90< 3	0.017 - 0.76	a) 5 - 62 b) 35 - 160	WS, ME, EP
2. Phosphoric Acid (Thermal)	Mass Median-1.6	1.6 - 93	a) 3.4 - 30.2 b) 35 - 160	WS, ME, EP

TABLE 7.2-1 (Concluded)

Unit Operation	Particle Size	Outlet Grain Loading	Carrier-gas Flowrate	Control Equipment
b) Lime Hydrator	Mass Median-2.6 $\sigma = 8.5$			WS
c) Fertilizer				
1. Superphosphate Den and Mixer		0.09 - 0.15		WS

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* Actual cubic feet.

** MC - mechanical
EP - electrostatic precipitation
FF - fabric filter
WS - wet scrubber
SA - sonic agglomerator

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8. FUTURE PROBLEMS

The principal objective of this phase of the study was to predict future problems that will be created by particulate pollutants emitted from stationary sources up to the year 2000. In making these forecasts we have attempted to take into account the following factors:

a. Changes in production capacity
b. Improvements in control devices
c. Legislative or regulatory action to enforce installation of control equipment

To make these projections, it is necessary to obtain data or make assumptions regarding production trends, efficiency of currently installed control equipment, improvements in control devices, and net control in future years. Methods for obtaining the requisite data are discussed in the following sections.

8.1 Production

Historical production data were collected on each major particulate pollutant source for the 1947-1968 period. Additionally, published forecasts were obtained from the literature covering the 1968 through 1980 period for many of these sources. In making projections, the median published forecasts were used in some cases; in all cases, they were at least employed as check points.

Historical data were projected to the year 2000 by 10-year intervals, using a variety of computerized forecasting procedures. Time series projections were made, using both linear and exponential forms, while other projections were based on correlation analyses between annual production volumes and the Index of Industrial Production and the Gross National Product.

Altogether, forecasts were made of all significant particulate pollutant sources on ten different bases. The median values and ranges resulting from these different forecasting techniques were carefully examined and evaluated. If there was no particular reason to disbelieve the results of the computer forecasts, a median value was chosen. In other cases, still different forecasting methods were employed.

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Paint, asphalt, mineral products, lumber and cement, for example, were tied to forecasts of new construction activity, while fertilizer and grain production were keyed to per capita consumption trends. Coal combustion by electric utilities was based on a declining percentage of total energy production, brought about by a combination of improved generating efficiency and by greater eventual use of alternative energy sources.

8.2 Improvements in Control Devices

We have attempted to account for improvements in control devices by the development of a technological forecasting curve. Data reported by Moore regarding overall dust collection efficiency of control equipment for various equipment age groups were used in identifying trends in industry practice. 1/ The data reflect the collection efficiency of control equipment actually installed (and control techniques actually practiced) by power plants during a given time period; they are not necessarily related to design efficiencies or technical capabilities in existence at that time. Moore's data are as follows:

Year Installed	Overall Dust Collection Efficiency (%)
1940 - 1944	77.0
1945 - 1949	80.0
1950 - 1954	83.5
1955 - 1959	88.0
1960 - 1964	93.0

Estimates of current and projections of future air pollution control equipment sales reported in the literature were weighted according to their relative collection efficiencies to determine the overall expected dust collection efficiency for equipment installed during 1967, 1972, and 1977. These gave the following values:

Year Installed	Overall Dust Collection Efficiency (%)
1967	94.6
1972	95.7
1977	97.0

The eight points thus obtained were then plotted on normal probability graph paper, and a least-square regression line was computed. Figure 8.2-1 represents this regression line plotted on arithmetic graph

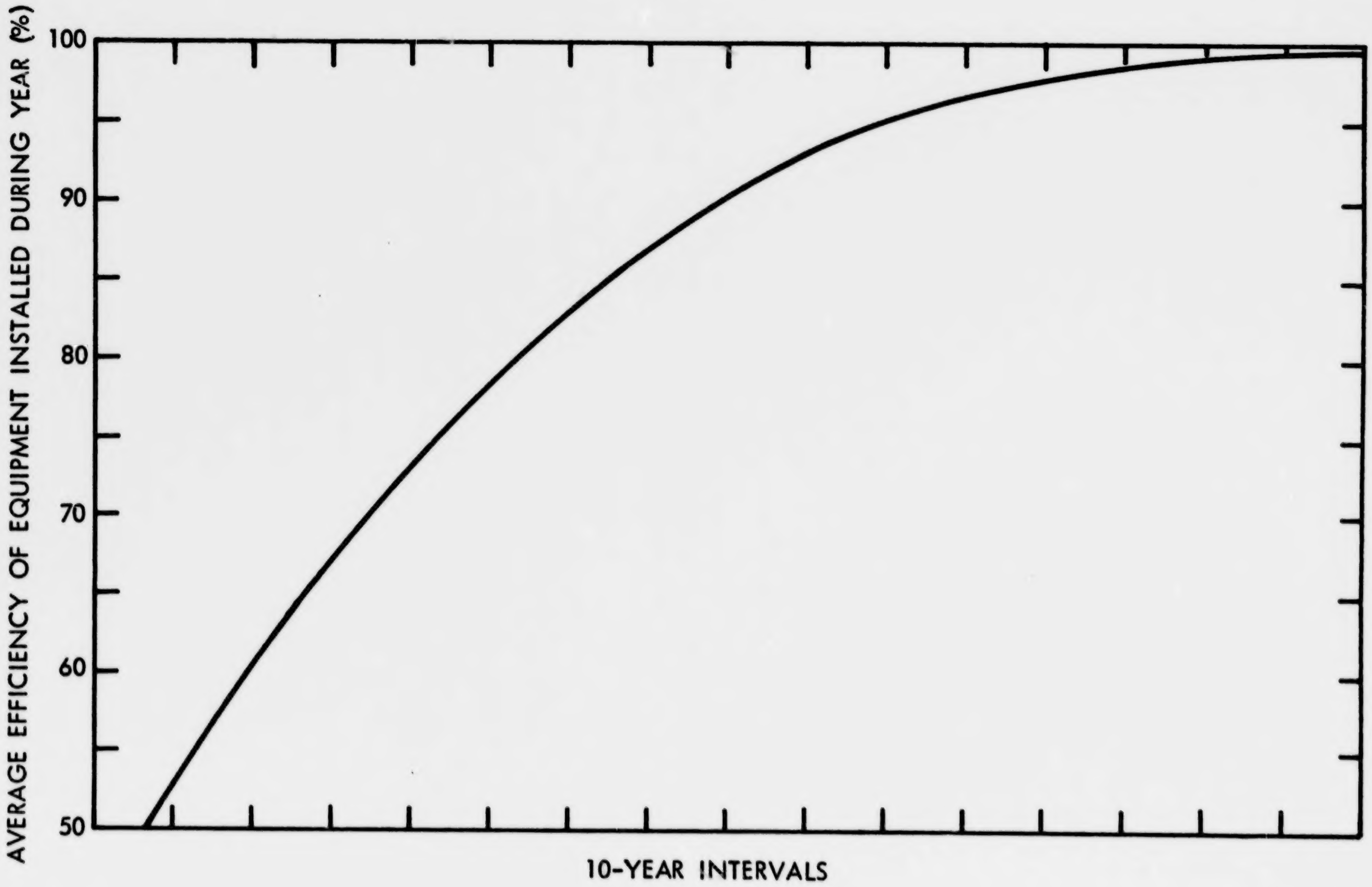

Figure 8.2-1 - Rate of Change of Efficiency of Installed Control Equipment

paper. A comparison between the values indicated by Figure 8-1 and the actual data points used in its development is as follows:

Year	Actual or Estimated Value (%)	Theoretical Value (%)
1942	77.0	76.0
1947	80.0	80.5
1952	83.5	85.0
1957	88.0	89.0
1962	93.0	92.0
1967	94.6	94.0
1972	95.7	96.0
1977	97.0	97.0

8.3 Currently Installed Equipment

The data on equipment sales by industry for the year 1967 were also used to estimate the efficiency of equipment presently being installed in each industry. Table 8-1 presents these estimates. The data based on sales were modified for those industries in which the sales of different types of control equipment do not accurately reflect actual practice. An example of this is petroleum production in which the cyclones on catalytic crackers are installed in series.

The efficiency figures in the right column are considered to be those attainable under optimum operating conditions. The left-hand column presents an engineering estimate of the efficiency attained under actual operating conditions.

The technological growth curve and the estimates on efficiency of currently installed equipment are input data for the various projection methods. The subsequent paragraphs describe the projection methods.

8.4 Projection Methods

Five methods have been selected to project the particulate emission burden to the year 2000. The first method considers no change in control above 1970 levels, while the other four methods reflect increasing pressure for improved control of particulate emissions.

Method 1 - In this method net control is assumed to be constant for each industry at the 1970 value through the year 2000. Production

TABLE 8-1

AVERAGE EFFICIENCY OF NEWLY INSTALLED AIR POLLUTION CONTROL EQUIPMENT BY INDUSTRY

Industry Description	Estimated Average Operating Efficiency*	Expected Efficiency at Optimum Conditions**
Coal-fired Electric Utilities	93.6	98.0
Coal-fired Industrial Boilers	90.0	95.0
Crushed Stone/Sand & Gravel	94.0	96.0
Agriculture Operations	92.0	94.0
Iron and Steel		
Ore Crushing	70.0	90.0
Materials Handling	95.0	97.0
Sinter Plants	95.0	97.0
Coke Ovens	70.0	90.0
Blast Furnaces	99.0	99.2
Open Hearth	----	----
Basic Oxygen	99.0	99.2
Electric Arc	99.2	99.2
Scarfing	95.0	97.0
Cement	97.7	98.4
Woodpulp	96.0	97.0
Lime	92.0	94.0
Clay	96.0	97.0
Primary Nonferrous		
Aluminum	85.0	90.0
Copper	97.0	98.0
Zinc	97.0	98.0
Lead	97.0	99.0
Phosphate Rock	97.0	98.5
Fertilizer	96.0	98.5
Asphalt	98.0	99.0
Ferroalloys	90.0	95.0
Iron Foundries	85.0	90.0
Secondary Nonferrous		
Copper	96.0	99.0
Aluminum	96.0	99.0
Lead	96.0	99.0
Zinc	96.0	99.0
Coal Cleaning	99.0	99.2
Carbon Black	----	----
Petroleum	99.999	99.999
Acids	94.0	96.0

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* Installed equipment operated under standard maintenance schedules.

** Installed equipment operated under optimum maintenance schedules.

capacity will vary, but the product of (efficiency of control) x (application of control) is constant.

Method 1 reflects a situation of no change in net control.

Method 2 - In this method application of control is assumed to increase linearly to 100% over the IRS plant lifetime. The efficiency of control equipment being installed each year is assumed to be constant and corresponds to the efficiency under estimated actual operating conditions as listed in Table 8-1. Equipment with this efficiency will be installed each year on replaced capacity, new capacity, and on some presently uncontrolled capacity to achieve the assumed linearity of application of control.

The rate of retirement of old plant capacity will be based on the guideline lives advocated by the Internal Revenue Service in its Publication No. 456, "Depreciation Guidelines and Rules." The economic lives indicated by the IRS guidelines are based on a considerable amount of historical data for each industry group, and probably represent the best information available regarding the actual retirement practices of industry. Any major deviations from the guidelines must be justified by a company's own records: that the established guidelines are widely accepted by industry offers ample evidence that they are adequately accurate.

Method 2 reflects activity to establish controls on all sources.

Method 3 - In this method application of control is assumed to increase linearly to 100% over the IRS lifetime and efficiency of new controls is increased based on technological growth curve. The efficiency of equipment being installed each year will be taken from Figure 8.2-1 with the starting point for each industry in 1970 assumed to be the efficiency under estimated actual operating conditions as listed in Table 8-1. As in Method 2, this equipment will be installed each year on replaced capacity (replaced following normal IRS lifetime), new capacity, and on some presently uncontrolled capacity to achieve the assumed linearity of application of control.

Method 3 reflects activity to establish controls on all sources and also improvements in control devices.

Method 4 - In this method application of control is assumed to increase linearly to 100% over the normal IRS lifetime, and the replacement period for old plant capacity is assumed to be 1/2 the normal IRS lifetime.

The efficiency of equipment being installed each year will be taken from Figure 8.2-1 with the starting point for each industry in 1970 assumed to be the efficiency under estimated actual operating conditions as listed in Table 8-1. This equipment will be installed each year only on replaced capacity (replaced following 1/2 normal IRS lifetime), new capacity, and on some presently uncontrolled capacity to achieve the assumed linearity of application of control.

Method 4 reflects activity to establish controls on all sources, improvements in control devices, and economic factors associated with installing control equipment on old plants.

Method 5 - In this method application of control is assumed to increase linearly to 100% by 1980. Replacement period for existing plants is taken as 1/2 the IRS lifetime. Efficiency of new controls is increased based on Figure 8.2-1 with starting point for each industry in 1970 assumed to be the optimum attained efficiency listed in Table 8-1.

This equipment will be installed each year only on replaced capacity (replaced following 1/2 normal IRS lifetime), new capacity, and on some presently uncontrolled capacity to achieve the assumed linearity of application of control.

Method 5 reflects activity to establish controls on all sources, improvements in control devices, economic factors associated with installing control equipment on old plants, and increasingly stringent emission standards.

8.5 Results

Results of the projection of particulate emissions for the major industrial sources are shown in Figures 8.5-1 to 8.5-27. Figure 8.5-1 presents a summation of all the major industrial sources. This figure shows that if there is no improvement in net control the emissions will increase from the present level of 18.0 x 10^6 tons/yr up to 52.6 x 10^6 tons/yr by the year 2000. This figure also illustrates the effect of four control strategies that would reduce emissions to between 2.7 and 8.4 x 10^6 tons/yr in the year 2000.

The major implication of the projection of particulate emissions is that emissions can be reduced by installation of control equipment on uncontrolled sources and,to a lesser extent, by shifts to more efficient types of collection equipment. Other conclusions are:

1) Emissions will rise at an alarming rate if additional and higher efficiency control equipment is not installed.

2) The most effective method of decreasing emissions is by increasing the application of control to 100%. Accomplishing 100% application of control by 1980 (Method 5) greatly reduces emissions, especially for those industries such as electric utilities and cement in which retirement of uncontrolled plants would take a greater number of years.

Increasing the application of control to 100% has a pronounced effect on industries in which present application of control is low, such as crushed stone. However, this low application of control exemplifies the control difficulties involved for these industries due to the numerous and varied sources of their emissions.

3) Emissions from many industrial sources tend toward an asymptotic value after 100% application of control is achieved. Thereafter, up to the year 2000, the installation of increasingly efficient equipment tends to stabilize the quantities emitted by offsetting increased production. After the year 2000, when advances in technology have increased efficiency to 99+%, emissions from most industries will follow production changes and may begin to rise accordingly.

Hot-mix asphalt plants and coal cleaning will be serious future problems because unlike most other sources the emissions begin to rise after about 1985 even with the most severe control measures.

4) The emissions from coal-fired industrial boilers, with no change in net control (Method 1), level off after 1980 as a result of decreased use of coal in industrial boilers. This fact is corroborated by phone conversations with many industrial boiler operators who stated that they have already converted to oil or gas, or intend to do so in the next 2 or 3 years.

5) The projected emissions from primary aluminum manufacture do not decrease as significantly as in other industries under the four control methods. This situation is a result of increasing production and process characteristics that limit the suitability of efficient control devices. Further research is needed to investigate effective means of controlling this source.

6) Potential future problem sources because of magnitude of controlled emissions are:

Sources	Emissions, Year 2000
Electric Utilities	0.7 to 3.5 x 10^6 tons/yr
Crushed Stone	0.4 to 1.0 x 10^6 tons/yr
Industrial Power	0.3 to 1.0 x 10^6 tons/yr
Cement	0.2 to 0.4 x 10^6 tons/yr
Iron & Steel	0.2 to 0.4 x 10^6 tons/yr
Agriculture	0.1 to 0.3 x 10^6 tons/yr
Lime	0.1 to 0.3 x 10^6 tons/yr
Woodpulp	0.1 to 0.3 x 10^6 tons/yr
Asphalt	0.1 to 0.2 x 10^6 tons/yr
Coal Cleaning	0.1 x 10^6 tons/yr

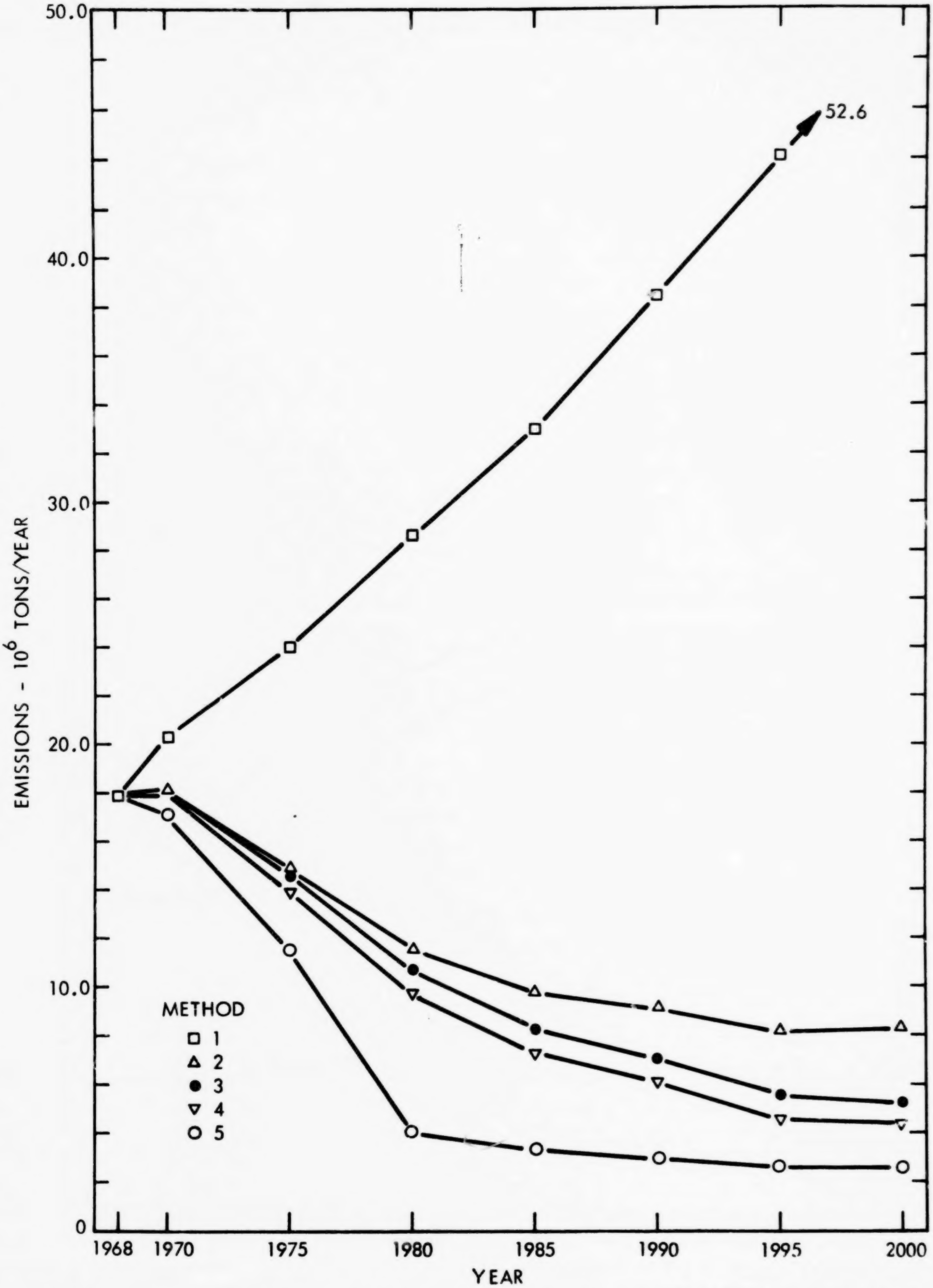

Figure 8.5-1 - Projections of Particulate Emissions - All Major Industrial Sources

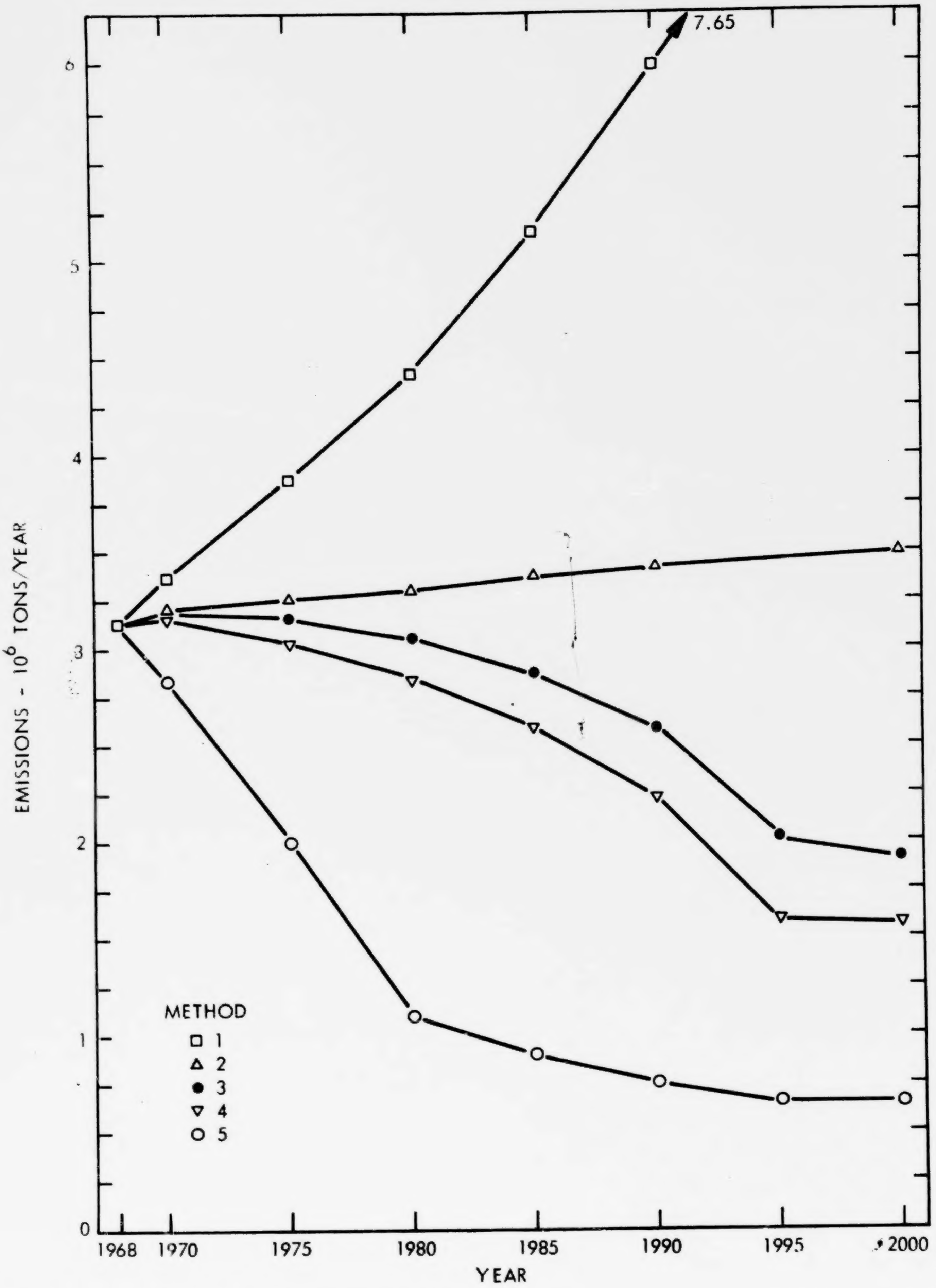

Figure 8.5-2 - Projections of Particulate Emissions - Electric Utilities Industry

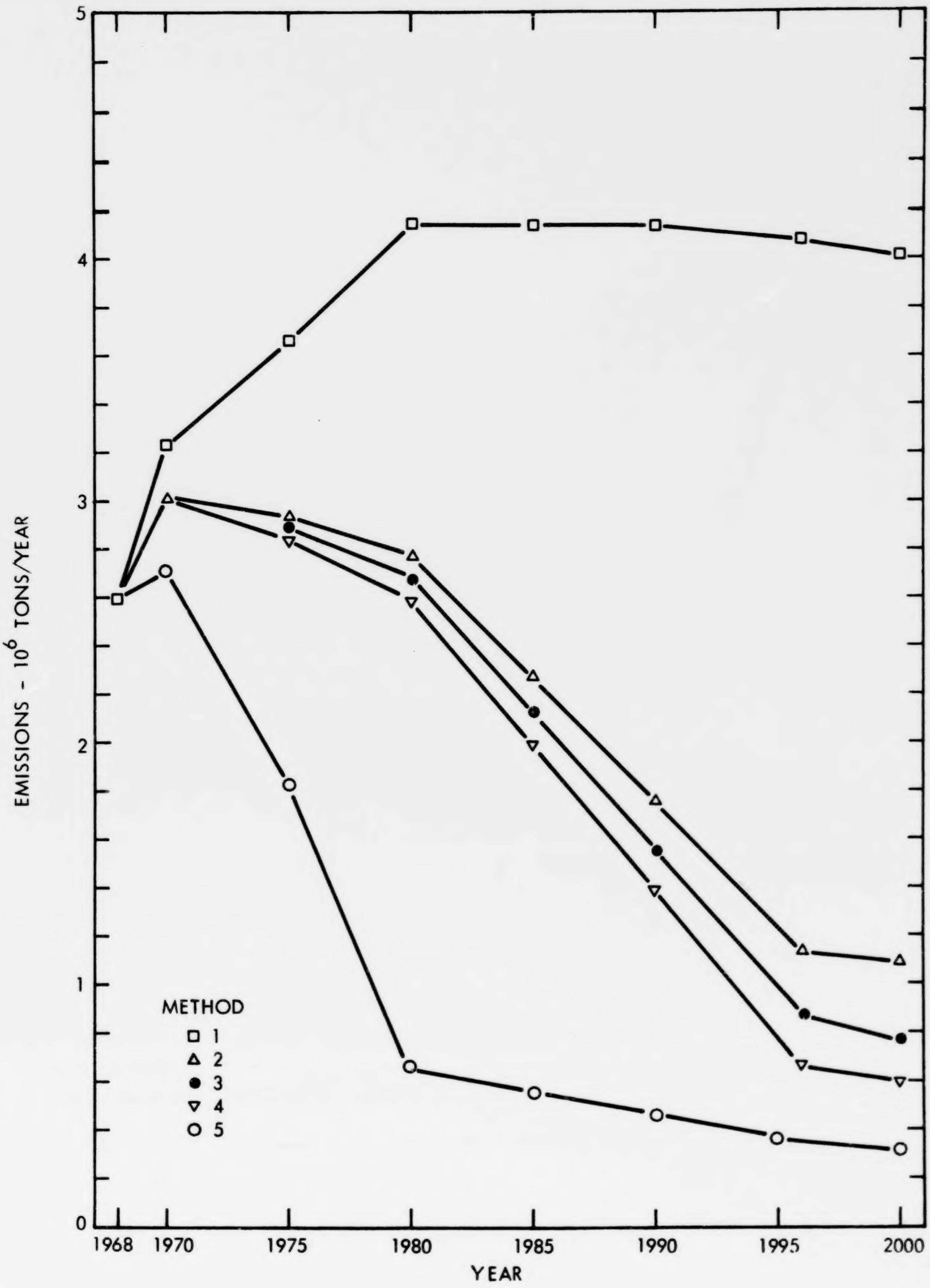

Figure 8.5-3 - Projections of Particulate Emissions - Industrial Power Gen. Industry

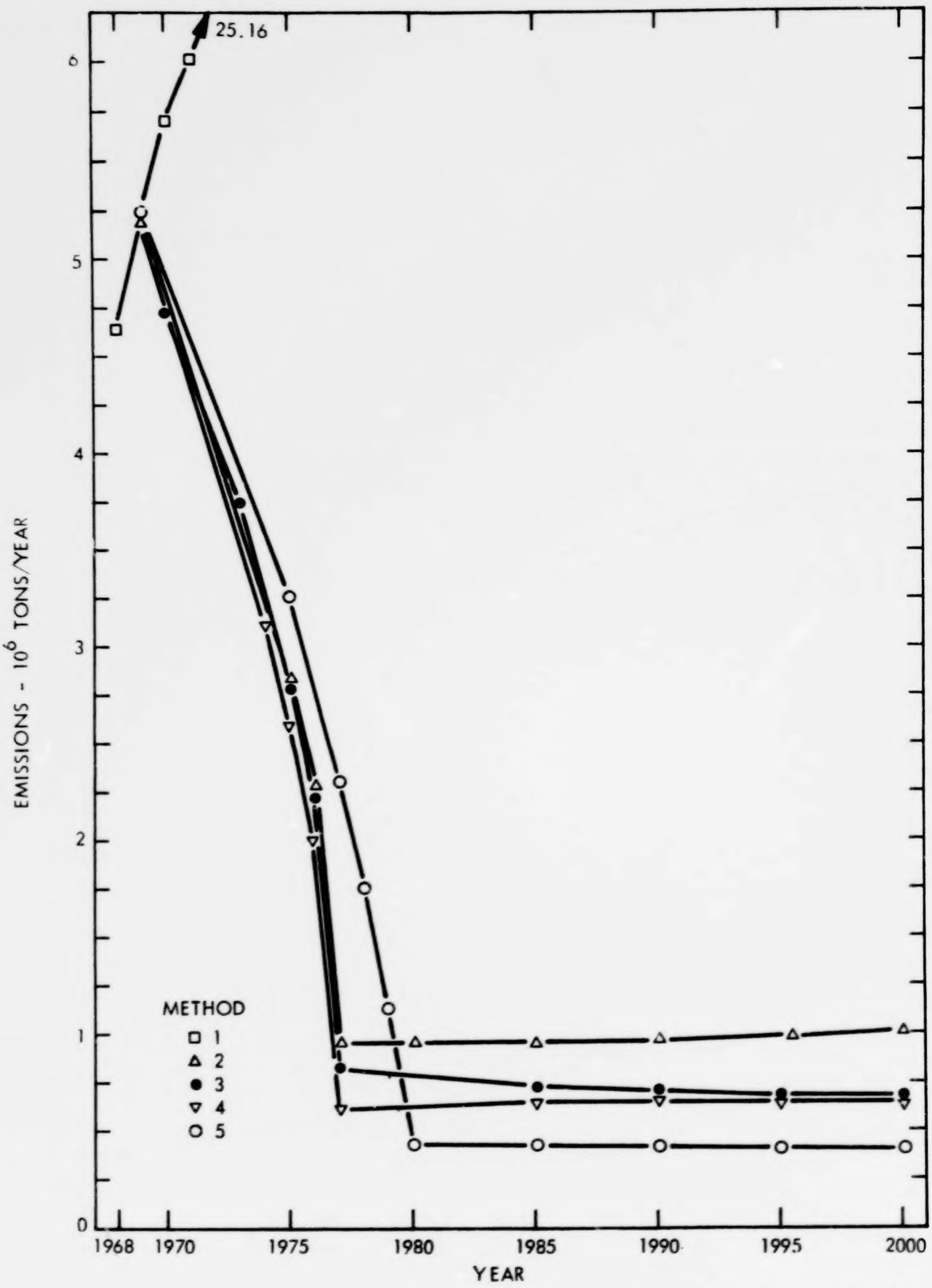

Figure 8.5-4 - Projections of Particulate Emissions - Crushed Stone/Sand/Gravel

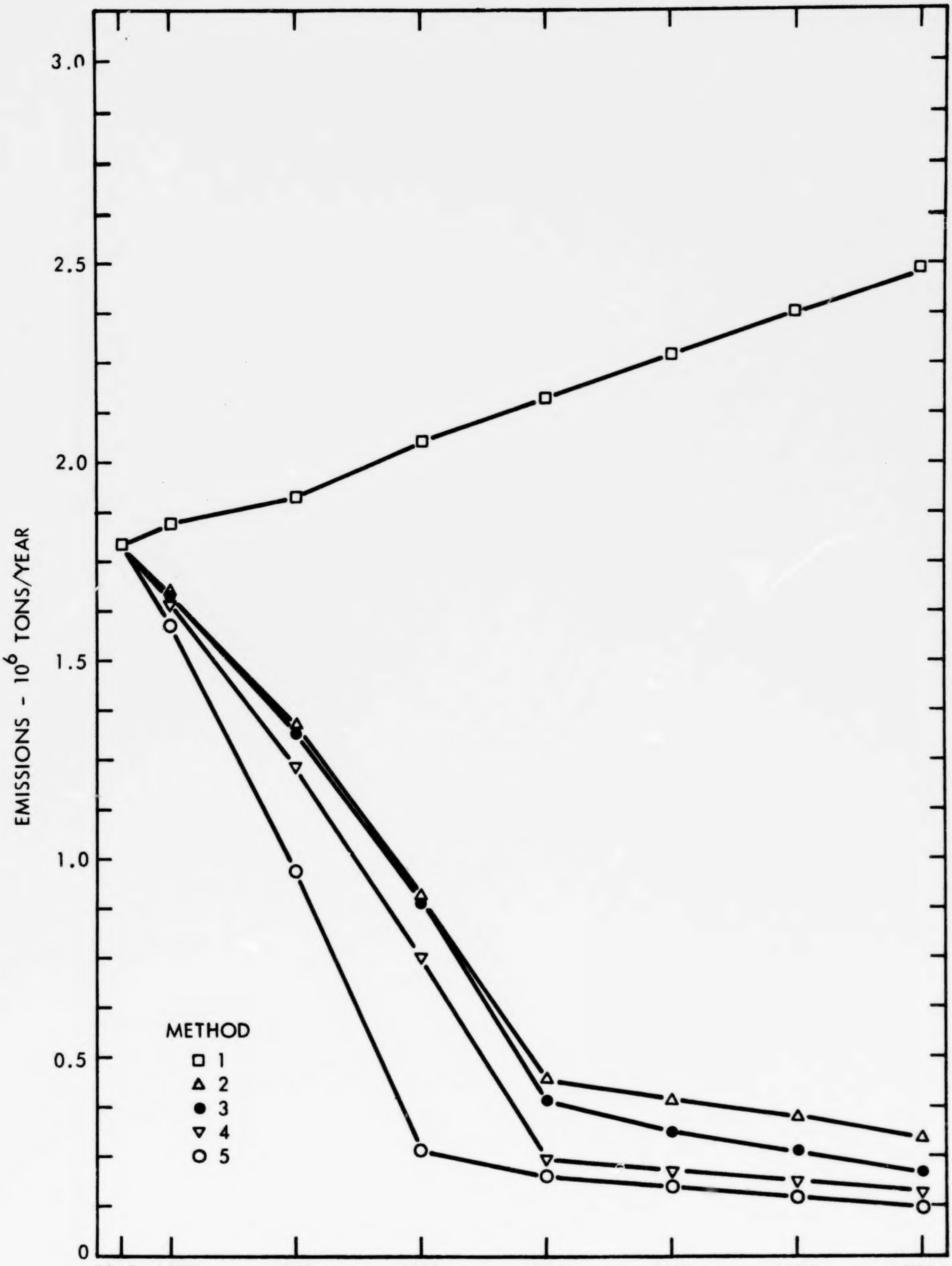

Figure 8.5-5 - Projections of Particulate Emissions - Agricultural Industry

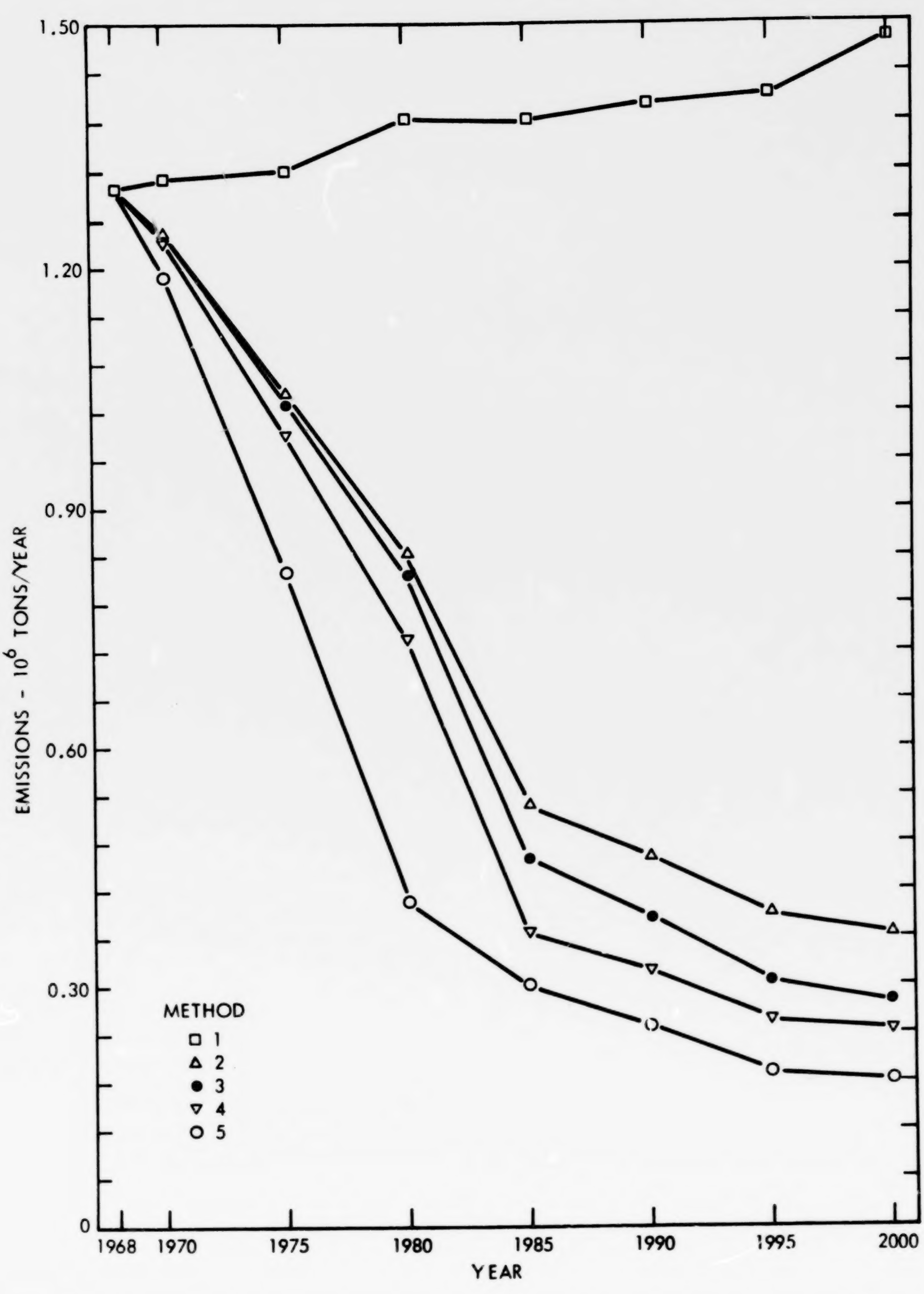

Figure 8.5-6 - Projections of Particulate Emissions - Iron and Steel

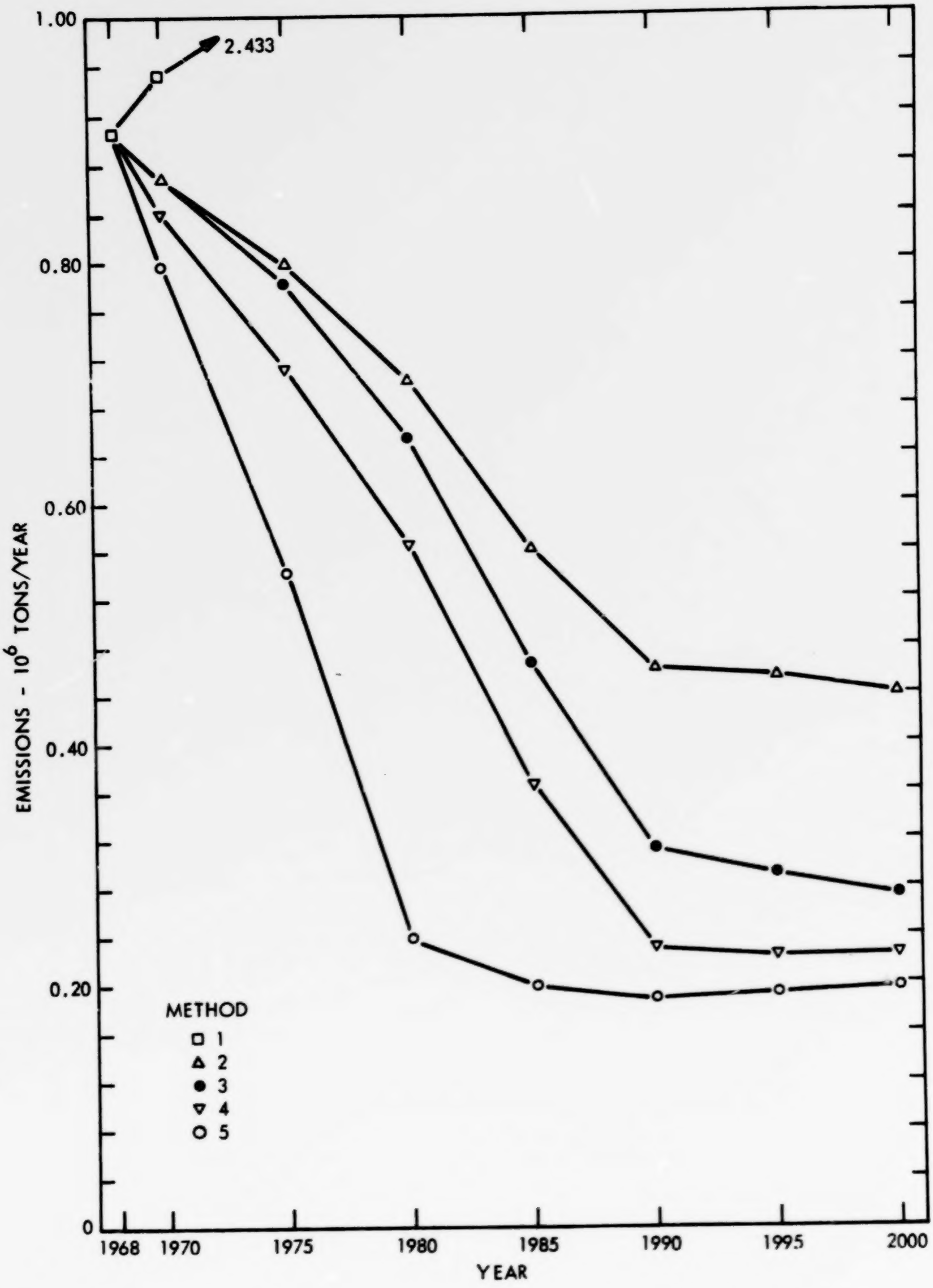

Figure 8.5-7 - Projections of Particulate Emissions - Cement

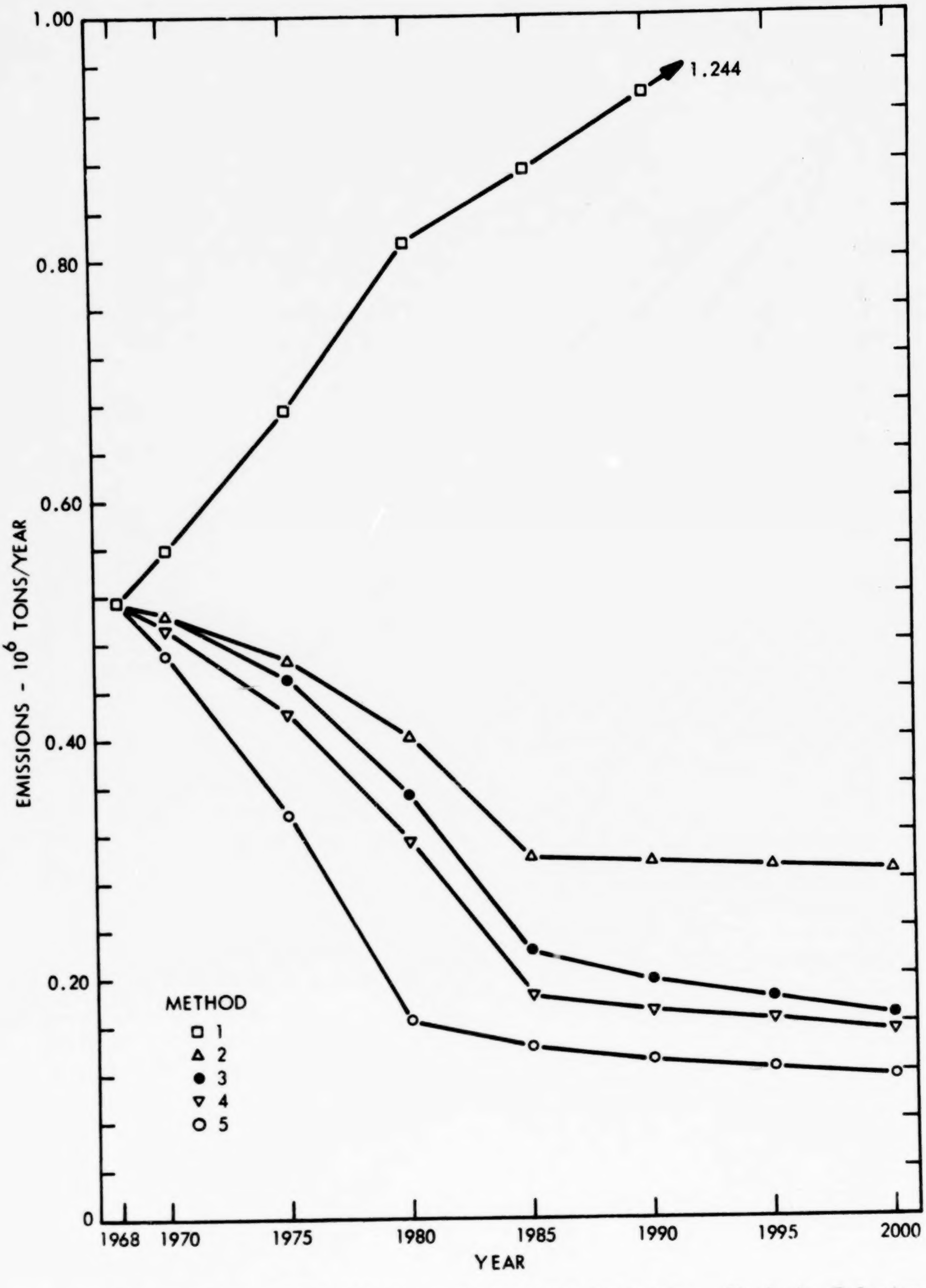

Figure 8.5-8 - Projections of Particulate Emissions - Woodpulp Industry

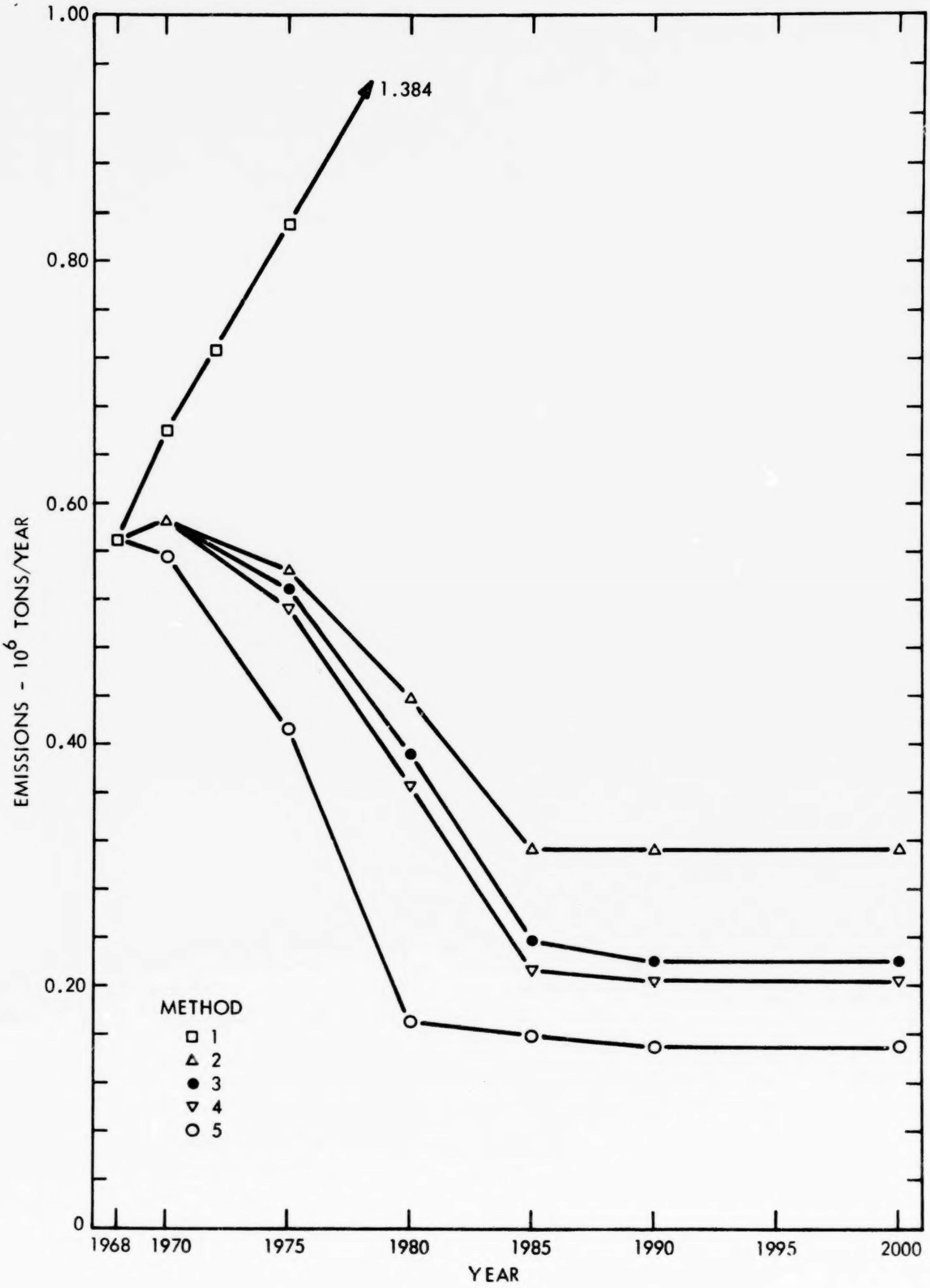

Figure 8.5-9 - Projections of Particulate Emissions - Lime

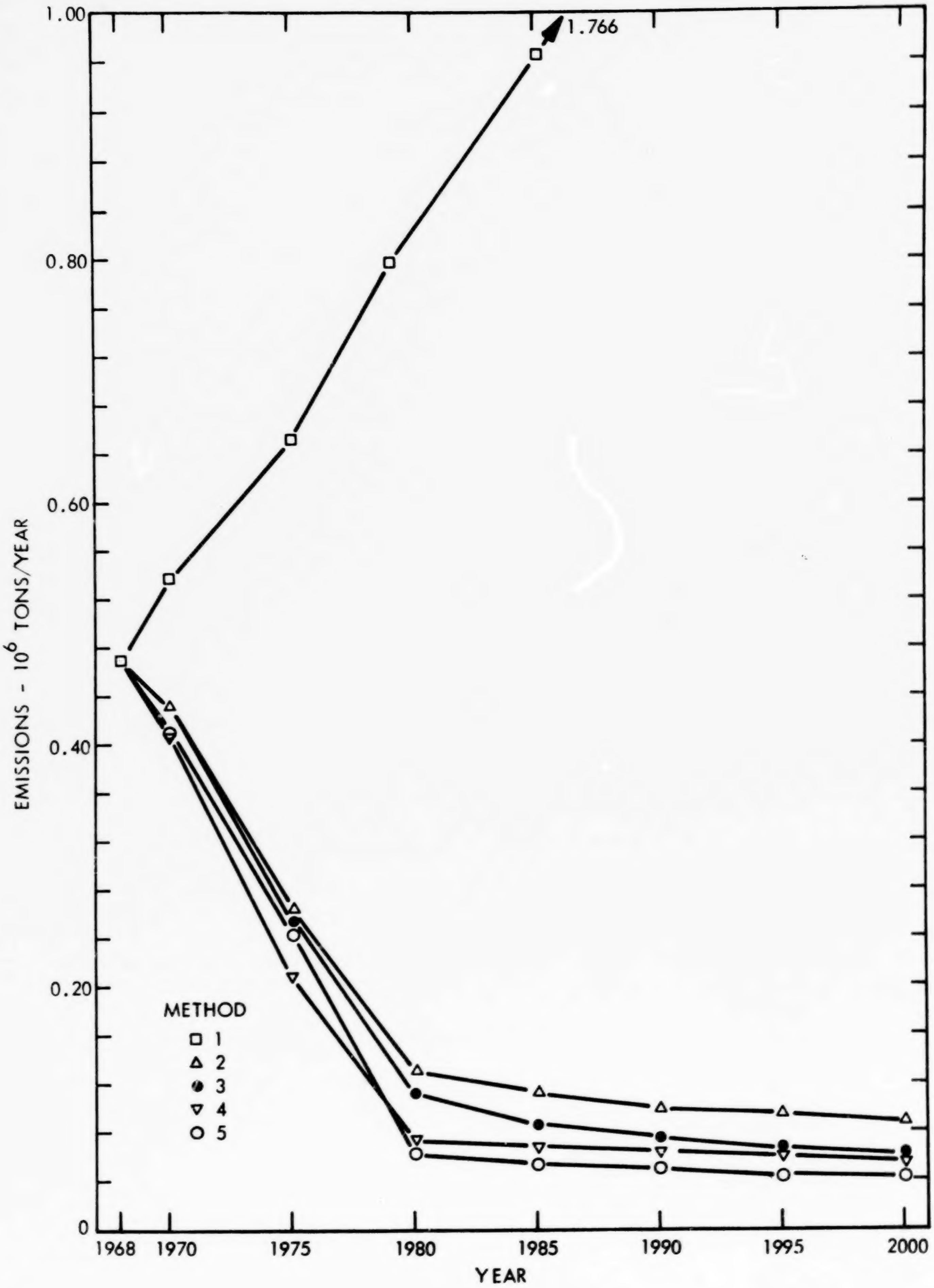

Figure 8.5-10 - Projections of Particulate Emissions - Clay

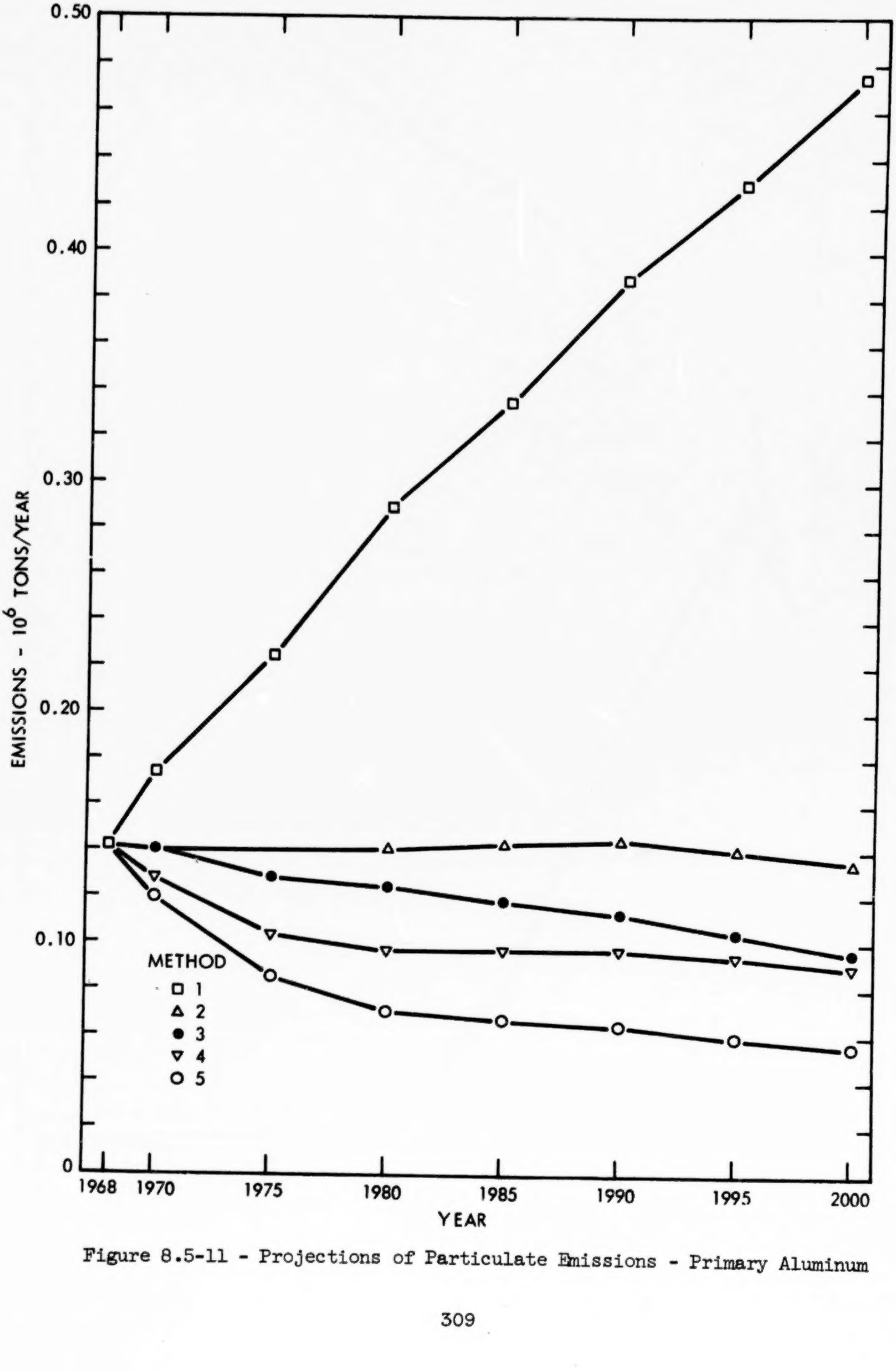

Figure 8.5-11 - Projections of Particulate Emissions - Primary Aluminum

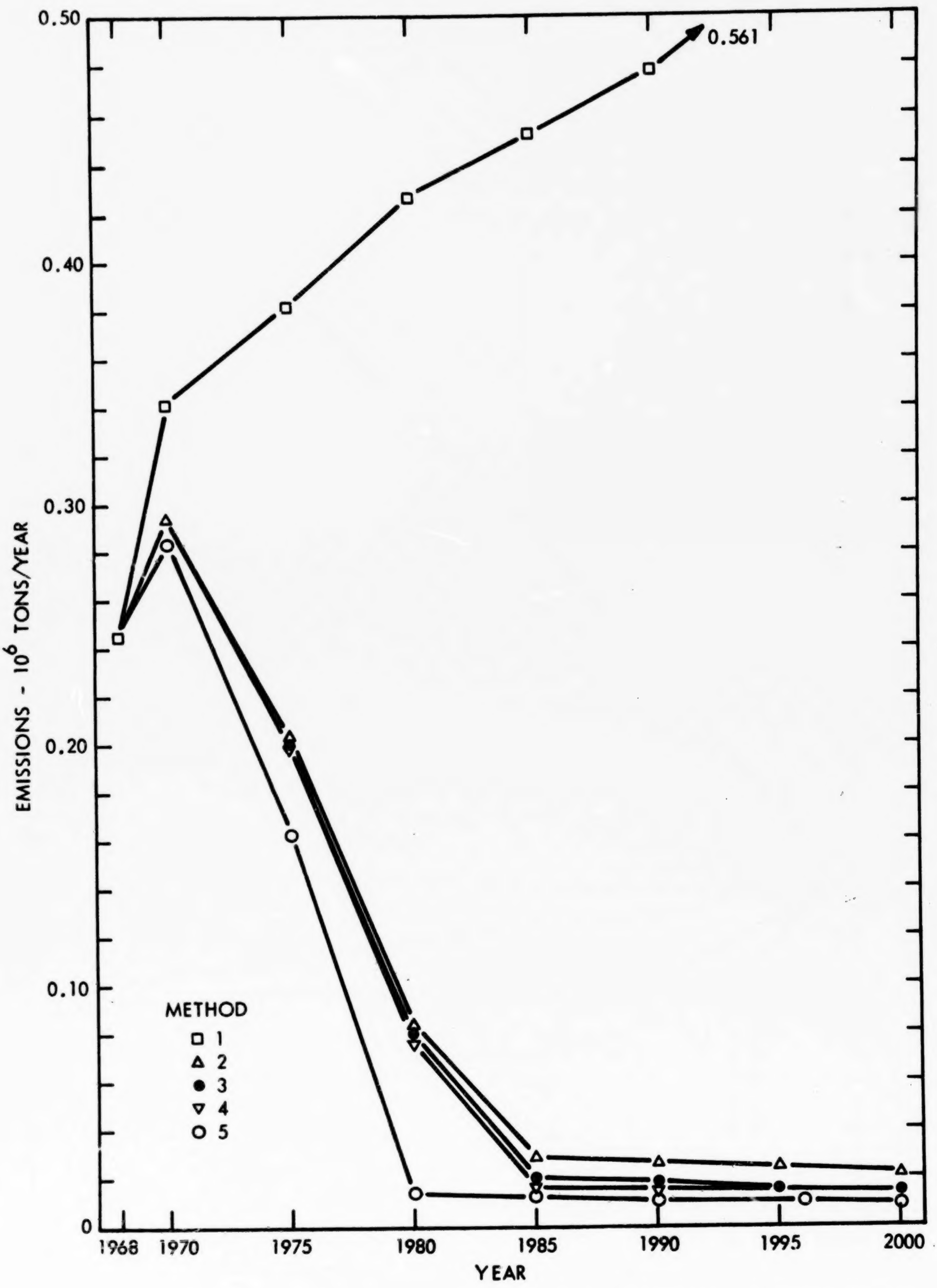

Figure 8.5-12 - Projections of Particulate Emissions - Primary Copper

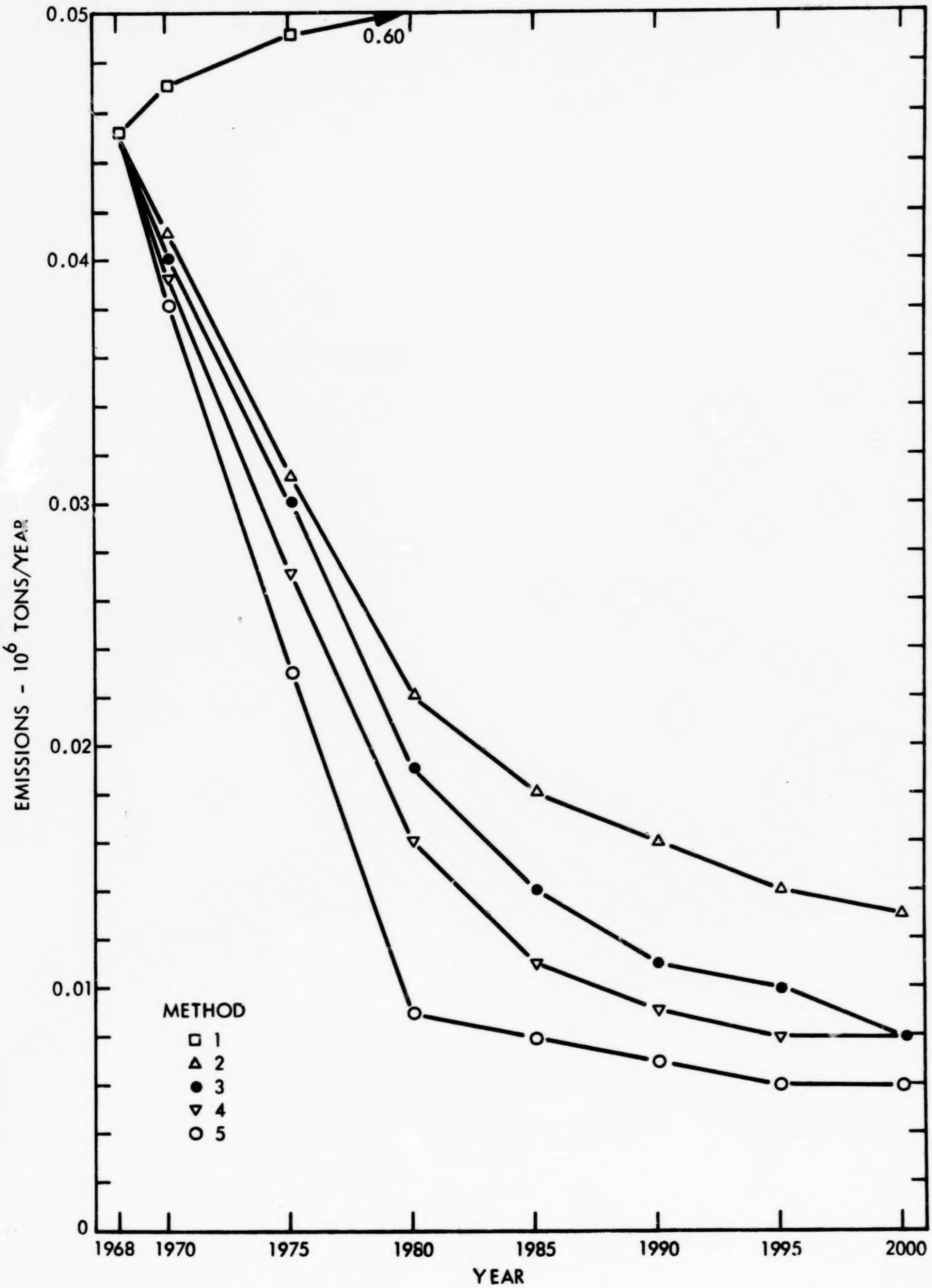

Figure 8.5-13 - Projections of Particulate Emissions - Primary Zinc

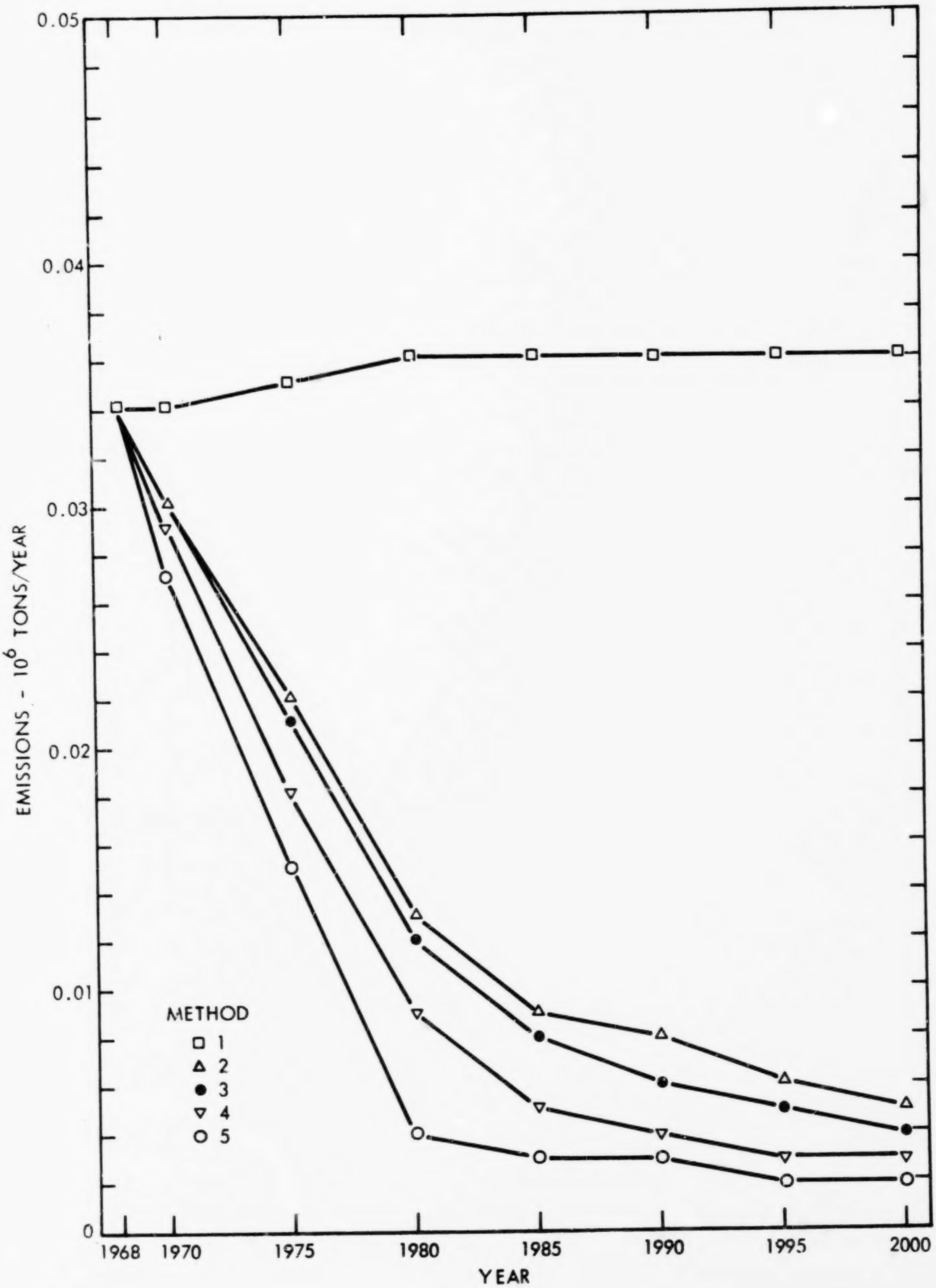

Figure 8.5-14 - Projections of Particulate Emissions - Primary Lead

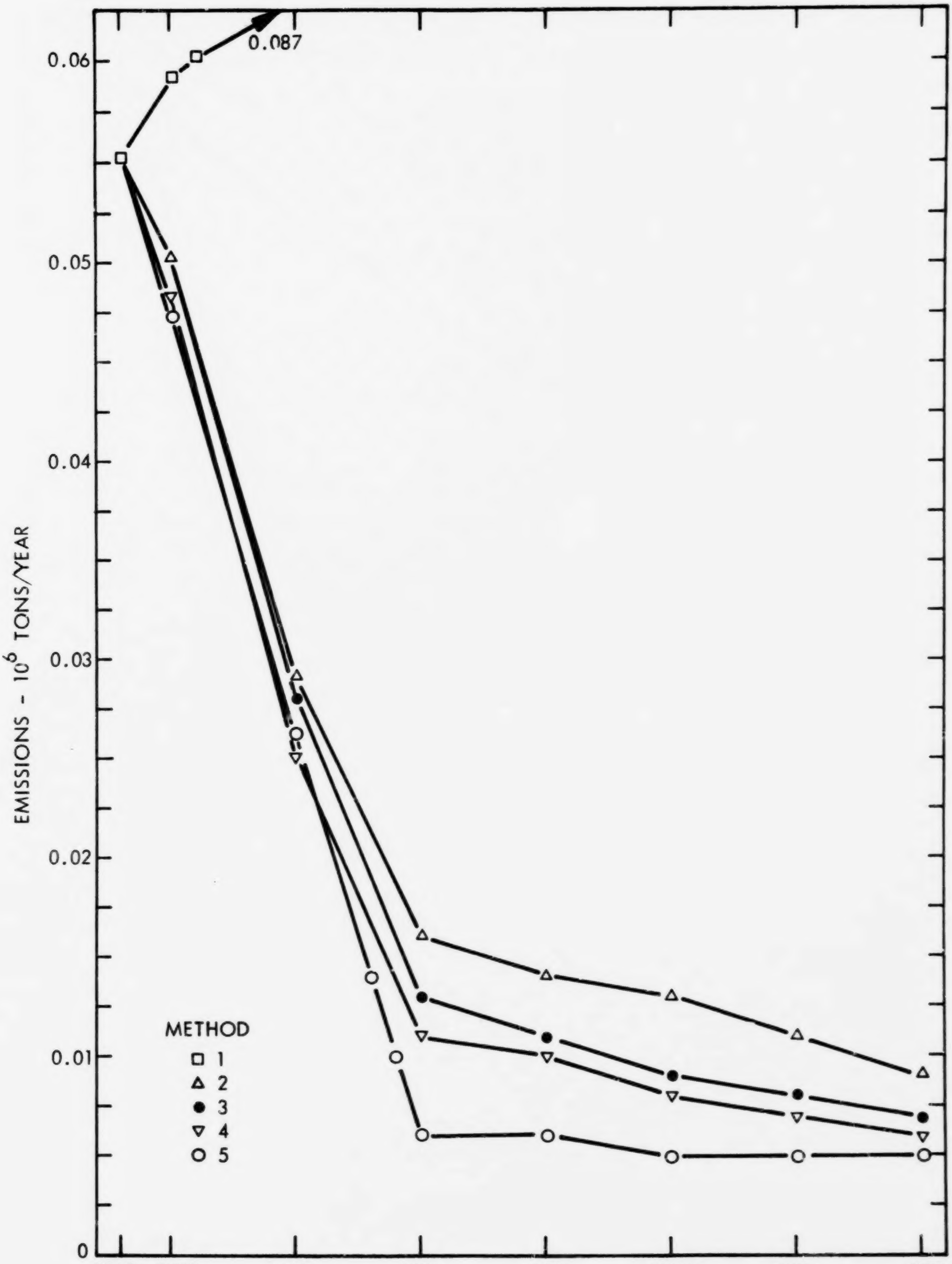

Figure 8.5-15 - Projections of Particulate Emissions - Phosphate Rock

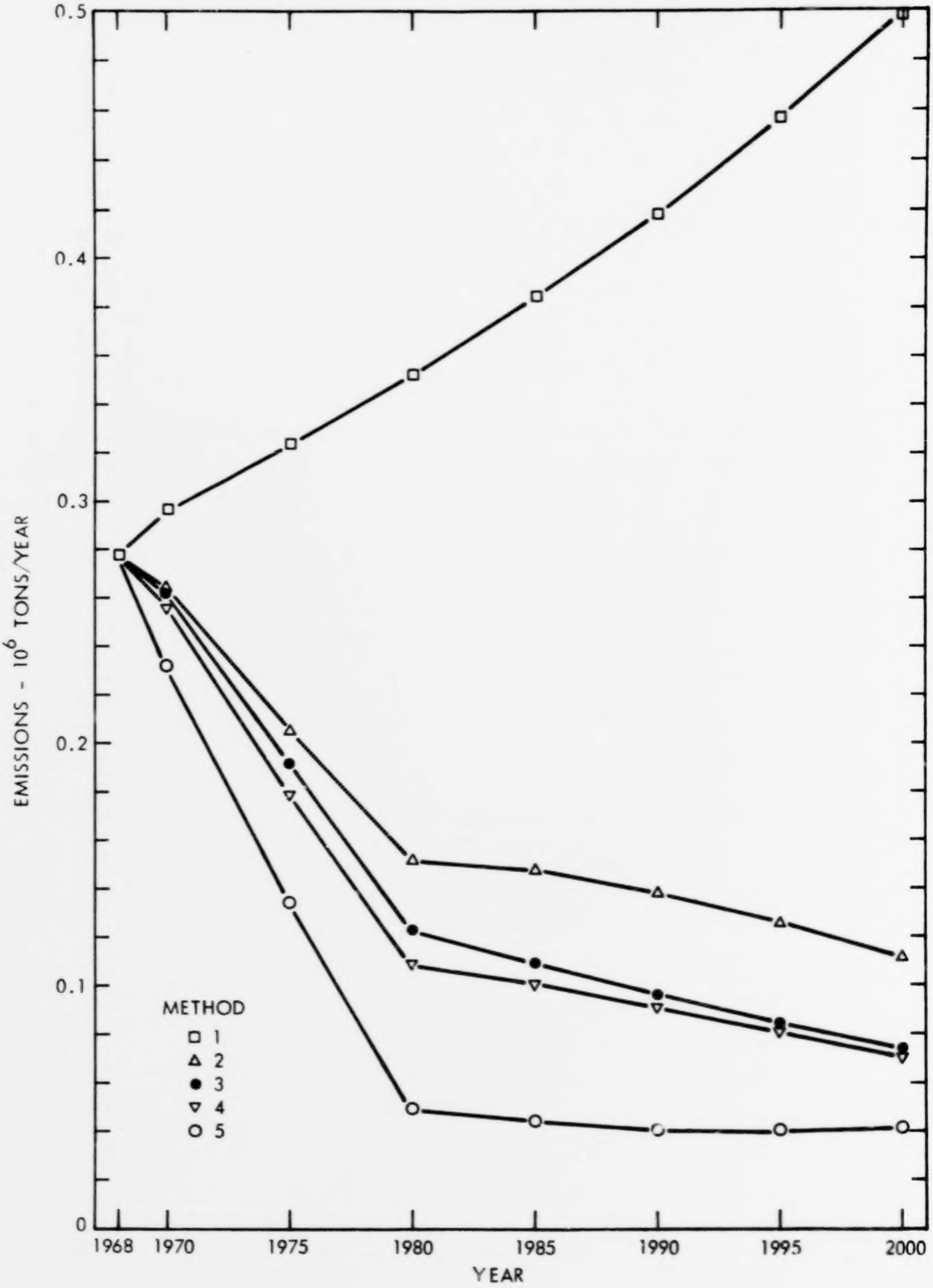

Figure 8.5-16 - Projections of Particulate Emissions - Fertilizer

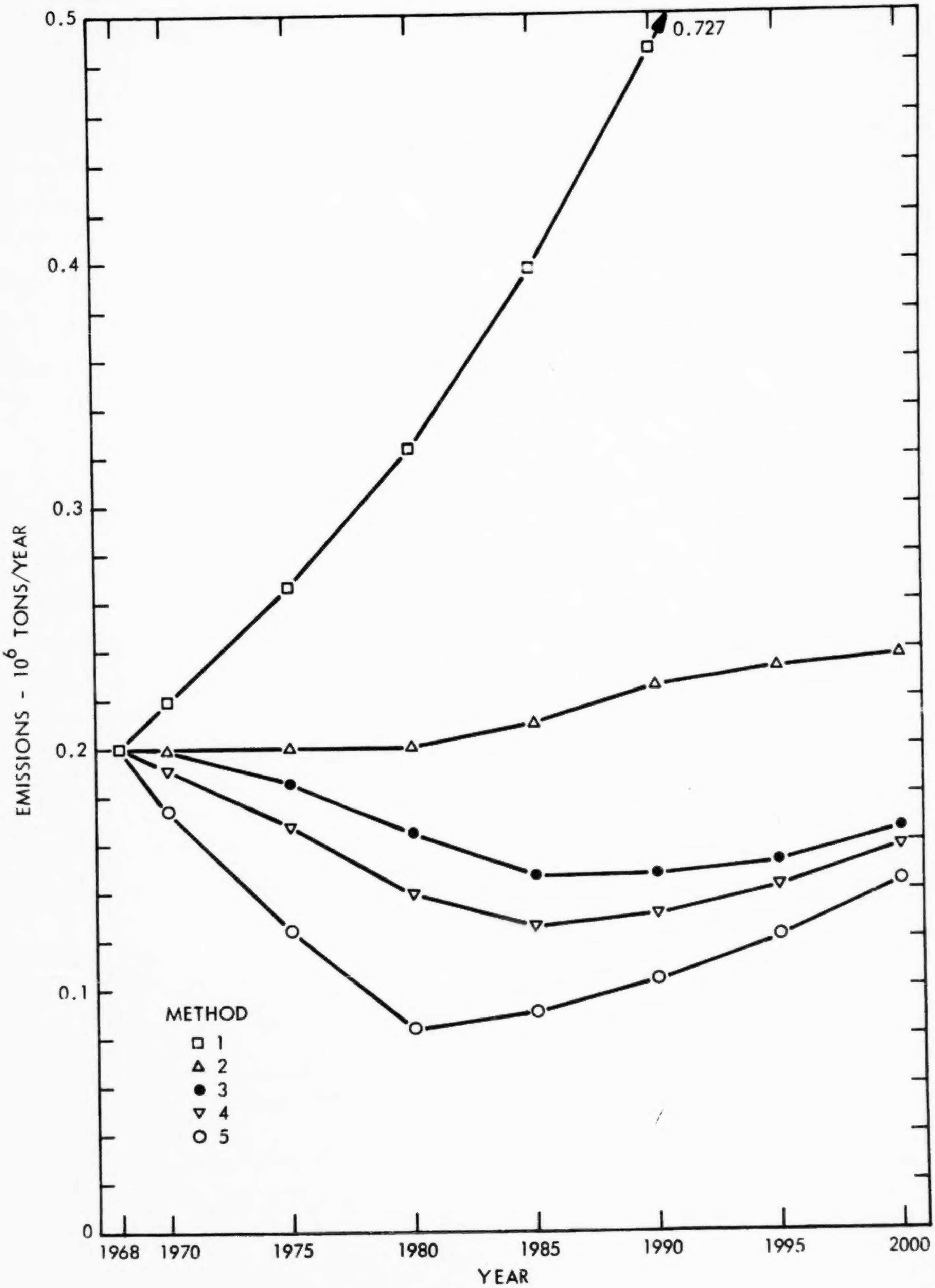

Figure 8.5-17 - Projections of Particulate Emissions - Asphalt

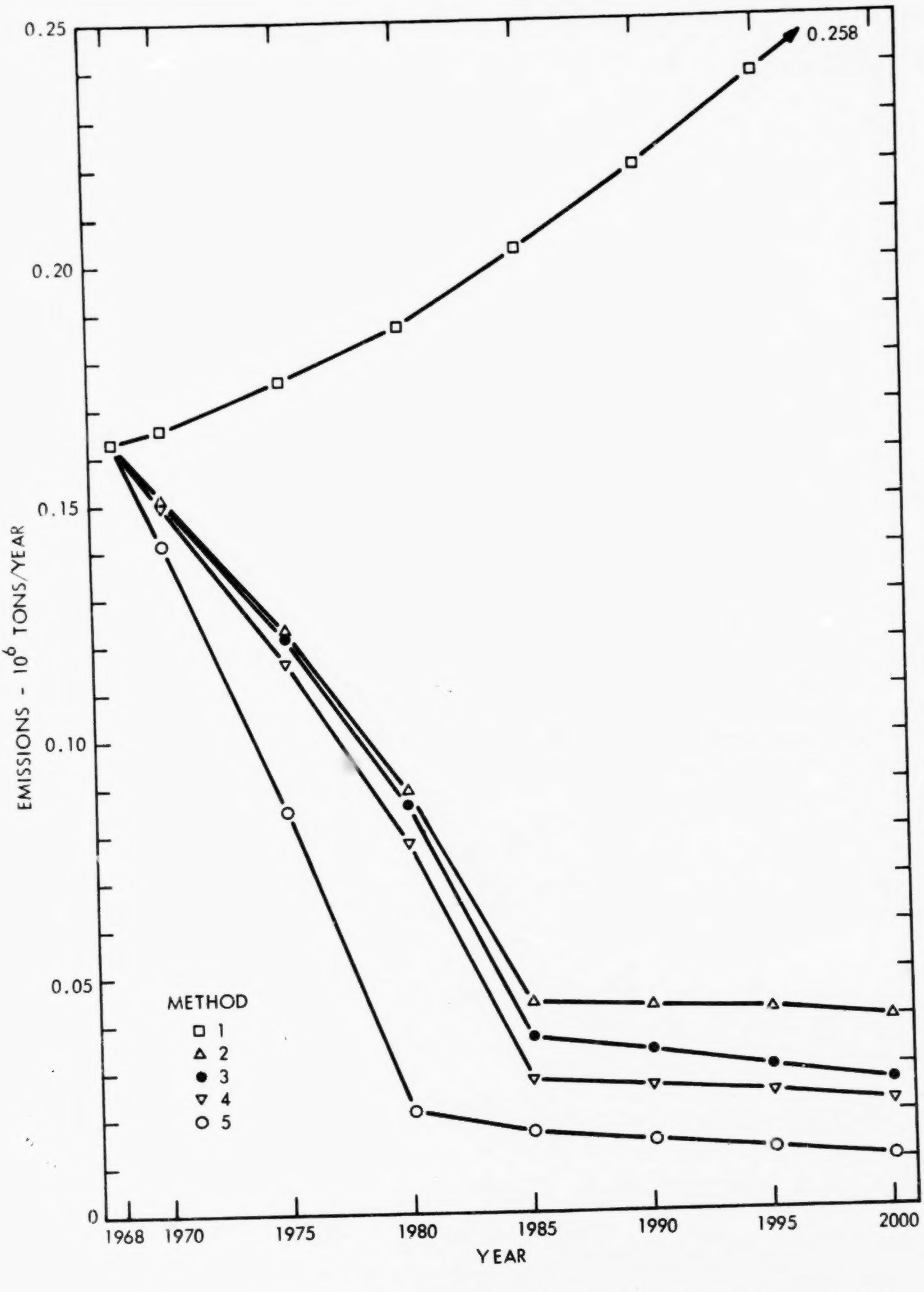

Figure 8.5-18 - Projections of Particulate Emissions - Ferroalloys

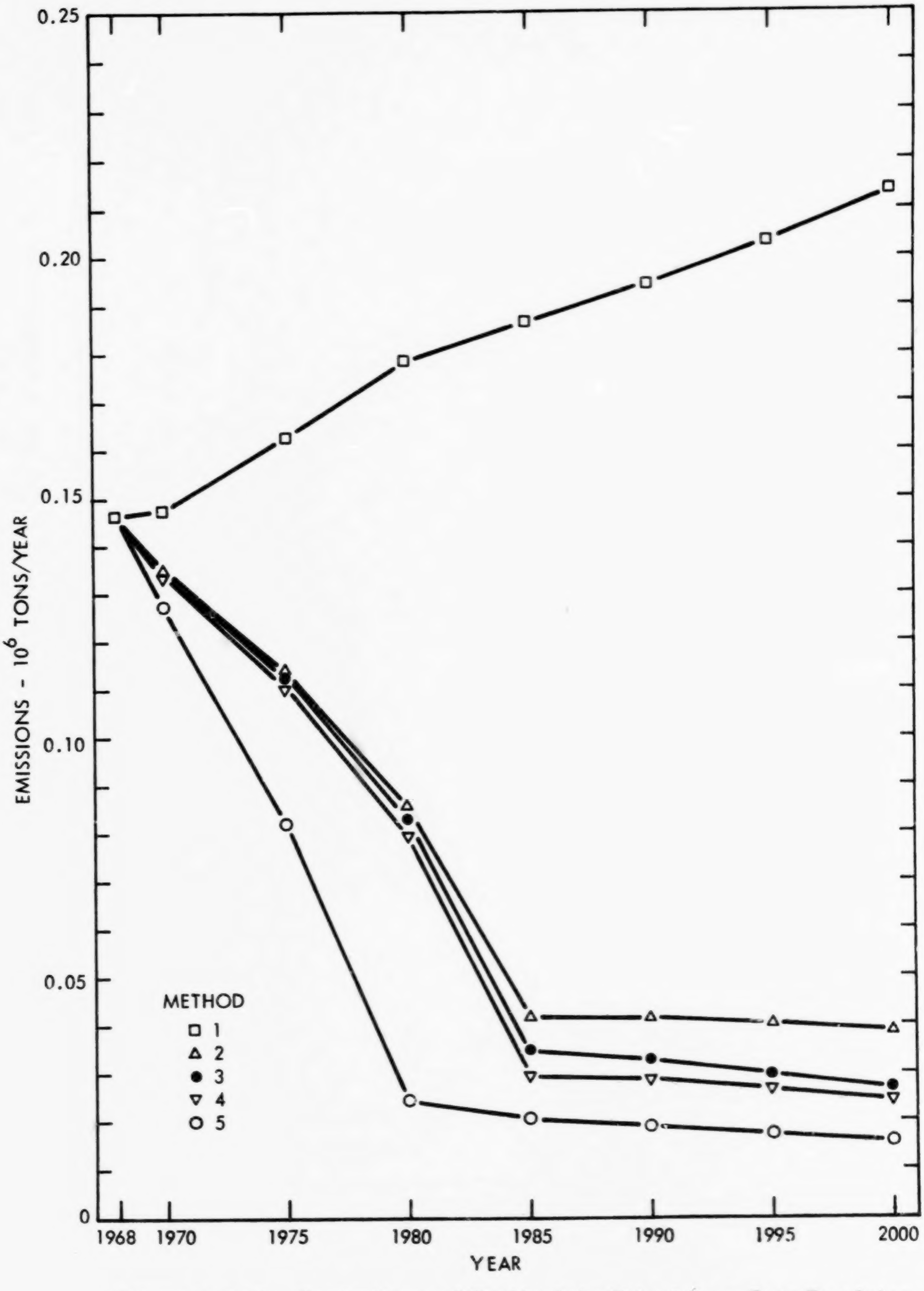

Figure 8.5-19 - Projections of Particulate Emissions - Iron Foundries

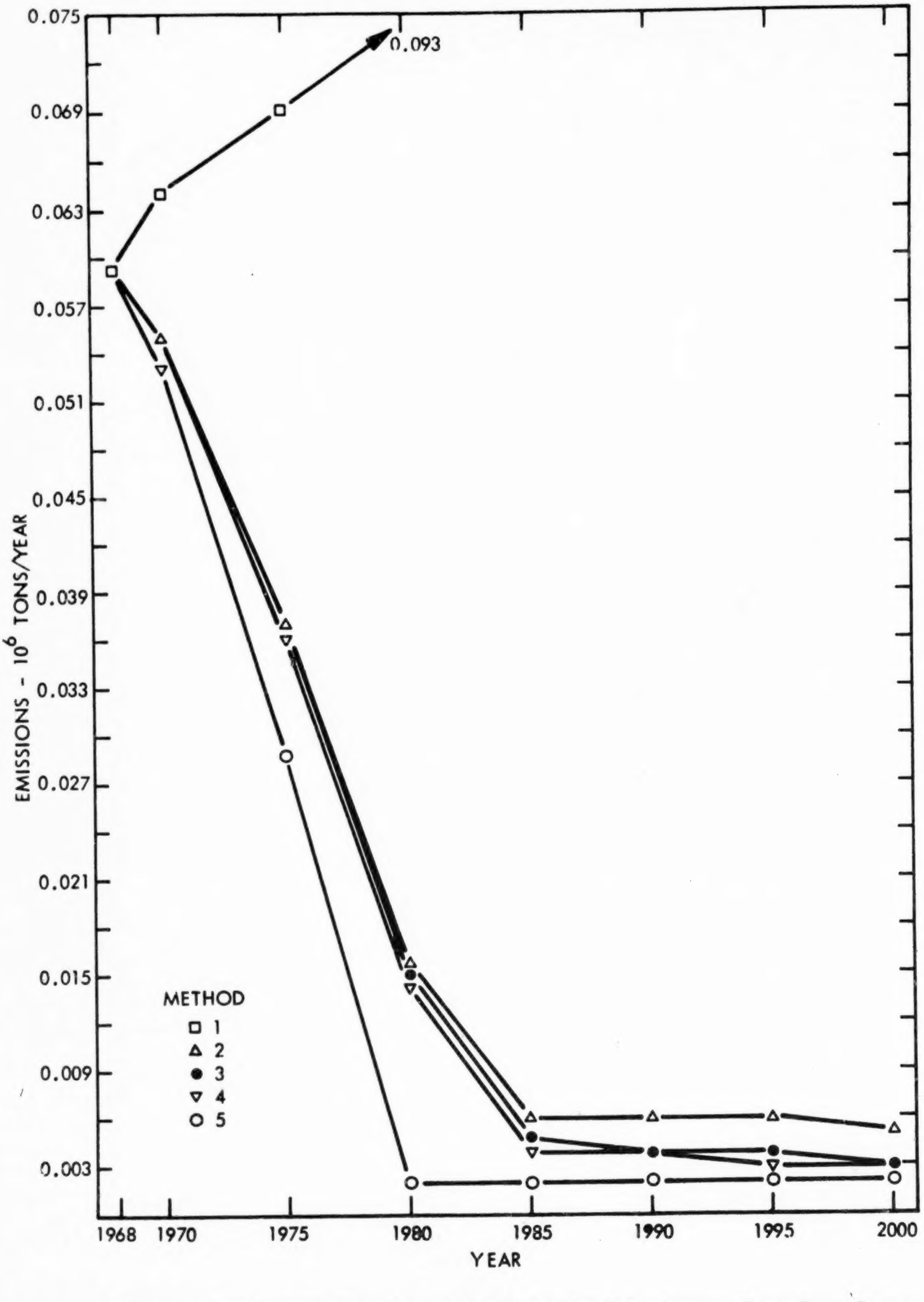

Figure 8.5-20 - Projections of Particulate Emissions - Secondary Copper

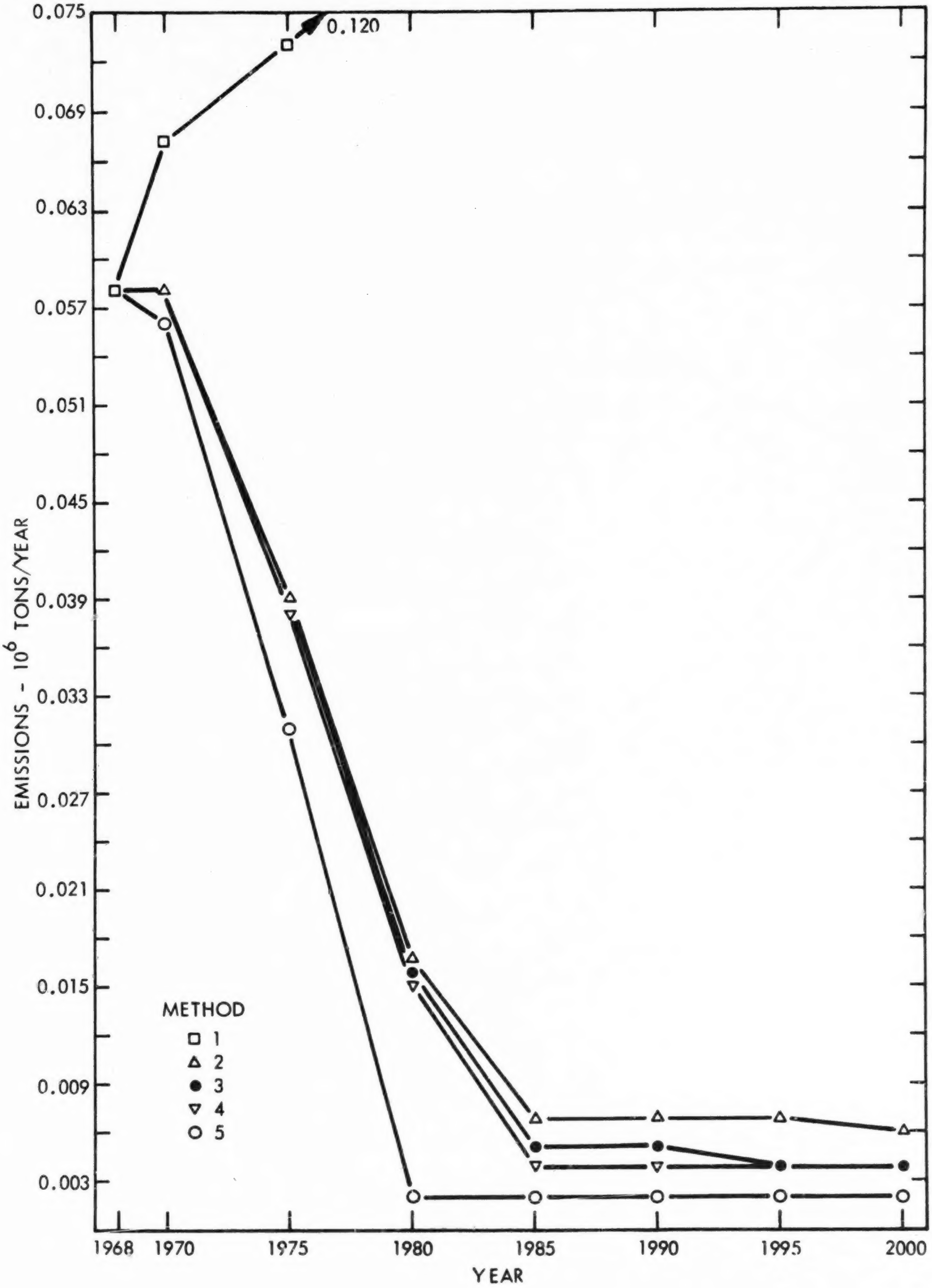

Figure 8.5-21 - Projections of Particulate Emissions - Secondary Aluminum

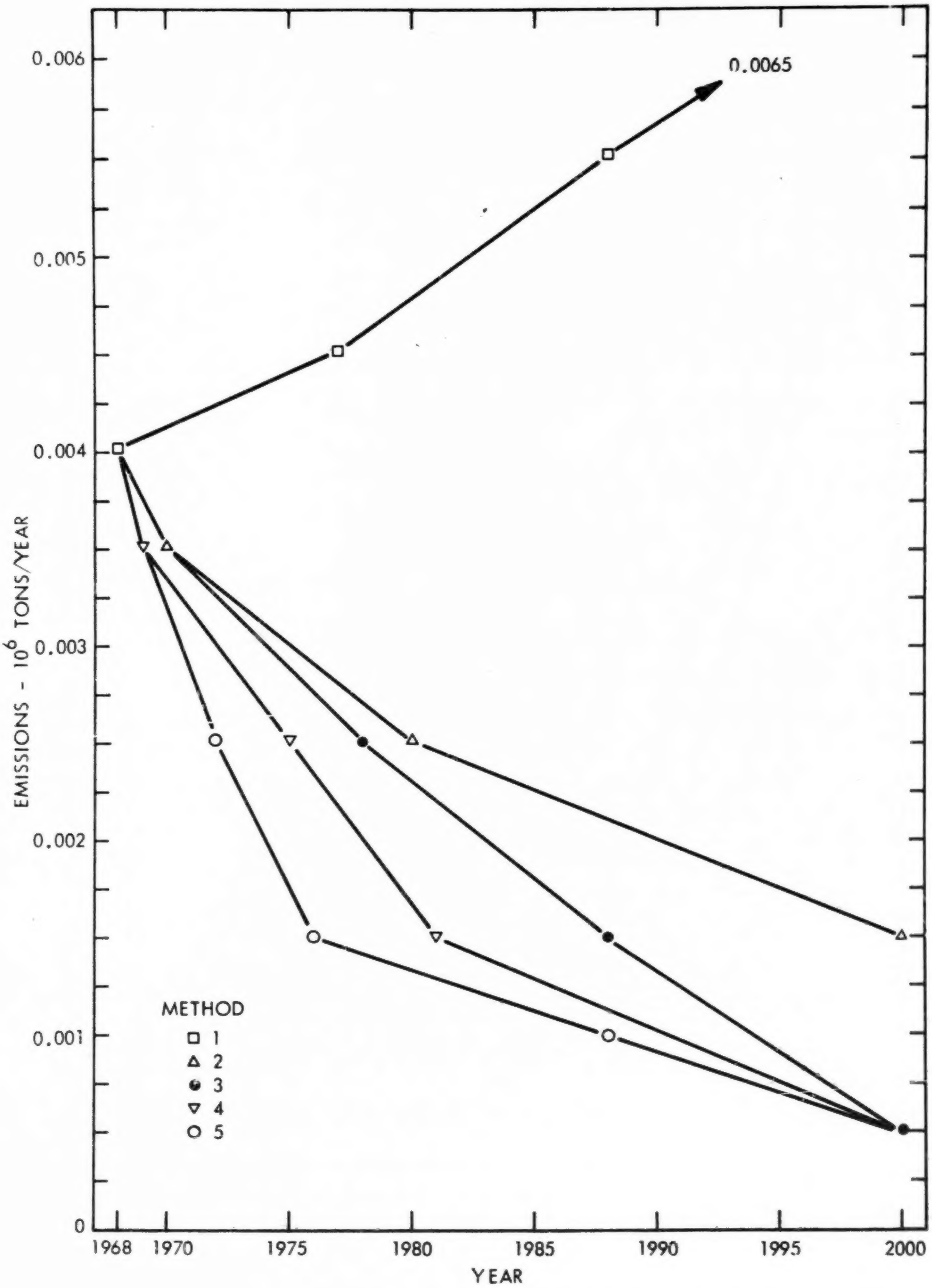

Figure 8.5-22 - Projections of Particulate Emissions - Secondary Lead

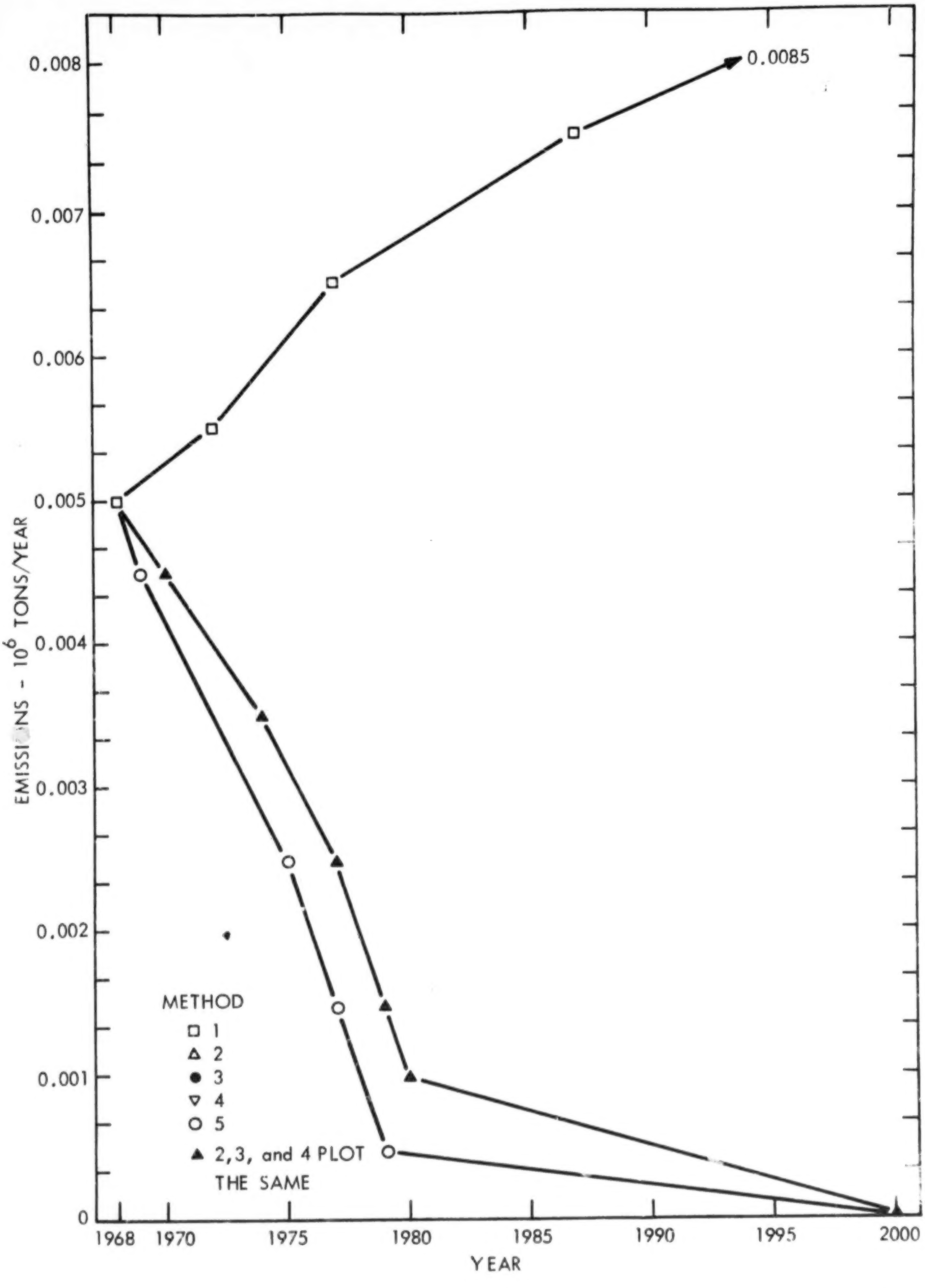

Figure 8.5-23 - Projections of Particulate Emissions - Secondary Zinc

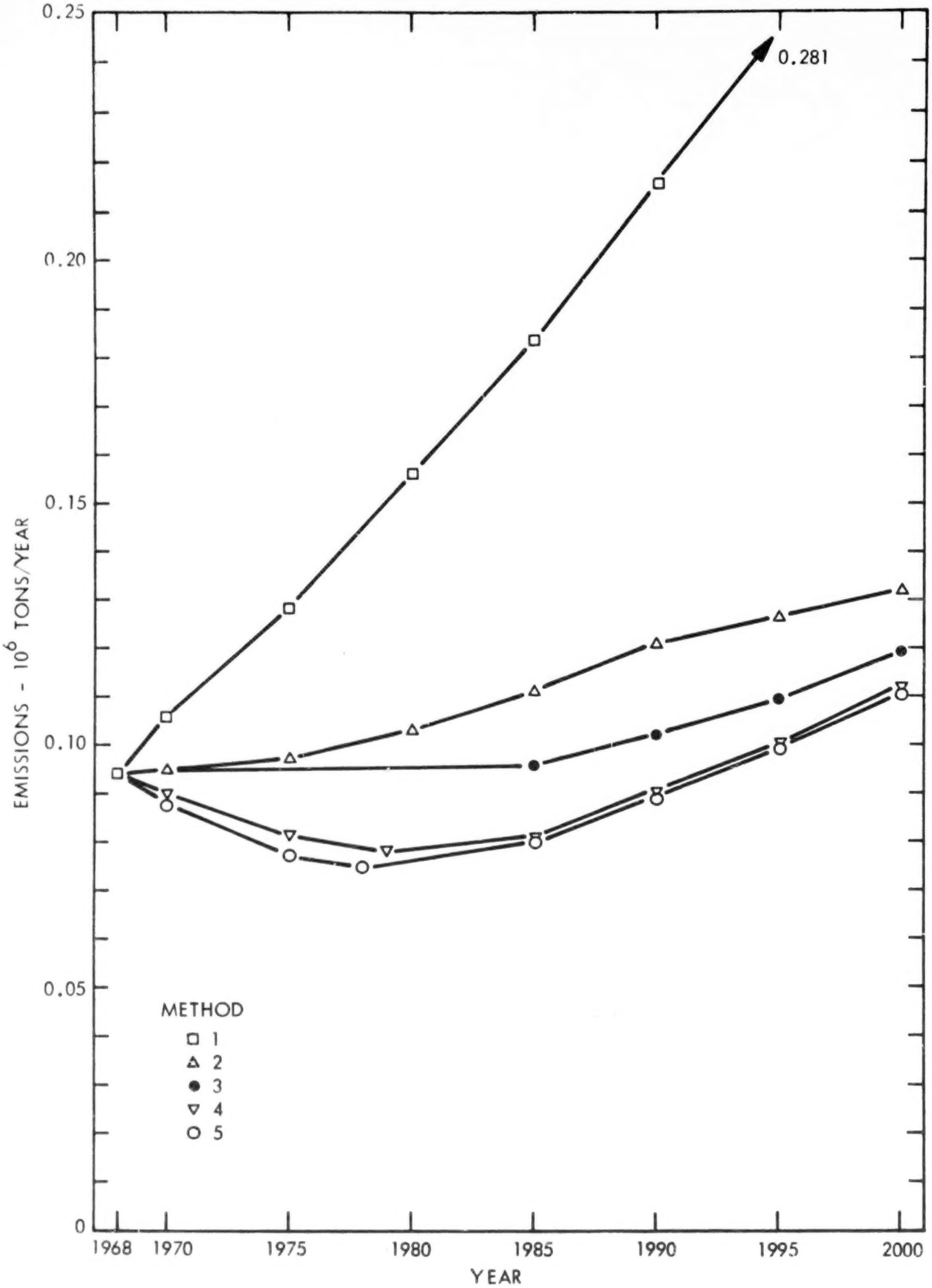

Figure 8.5-24 - Projections of Particulate Emissions - Coal Cleaning

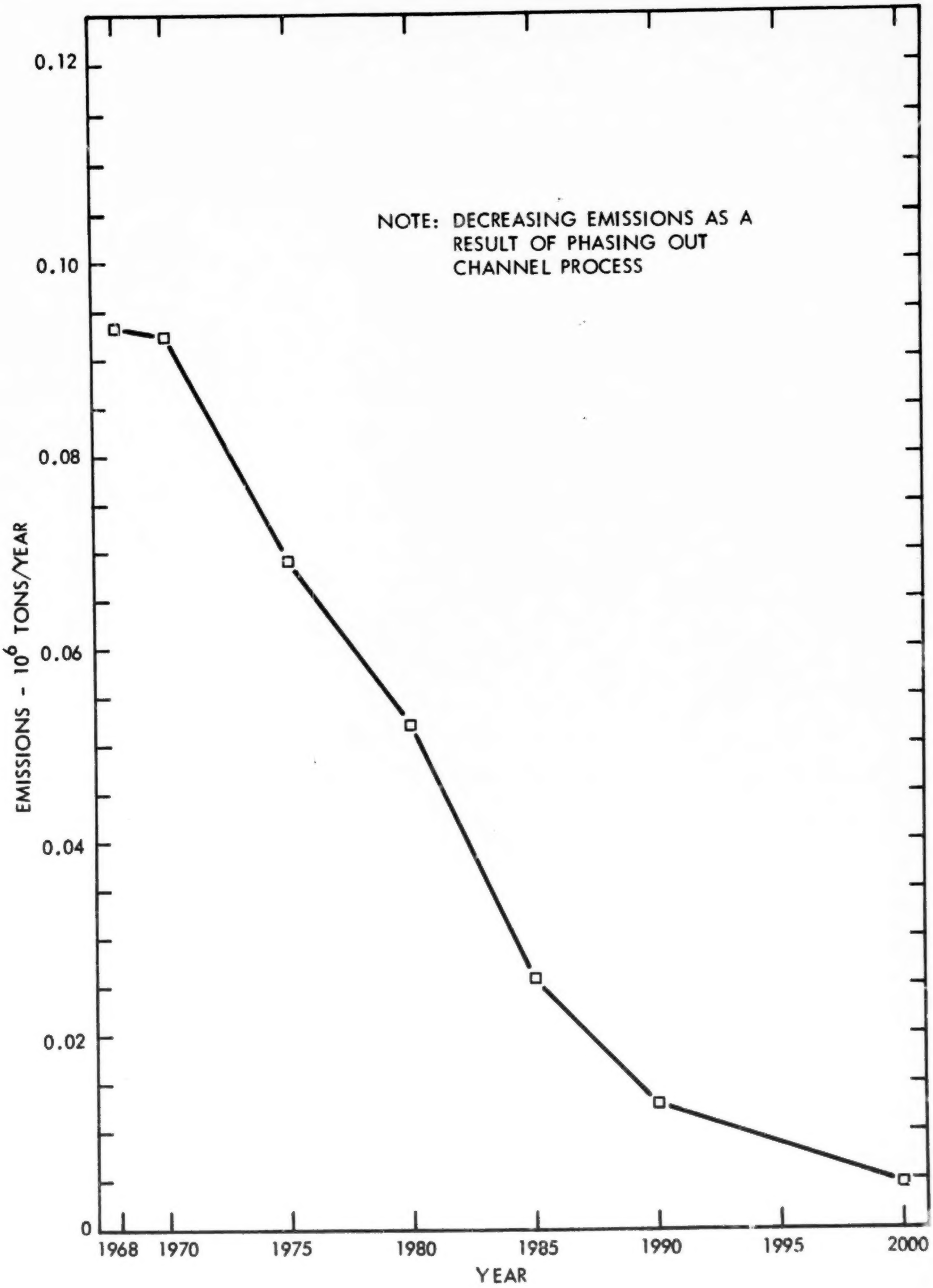

Figure 8.5-25 - Projections of Particulate Emissions - Carbon Black

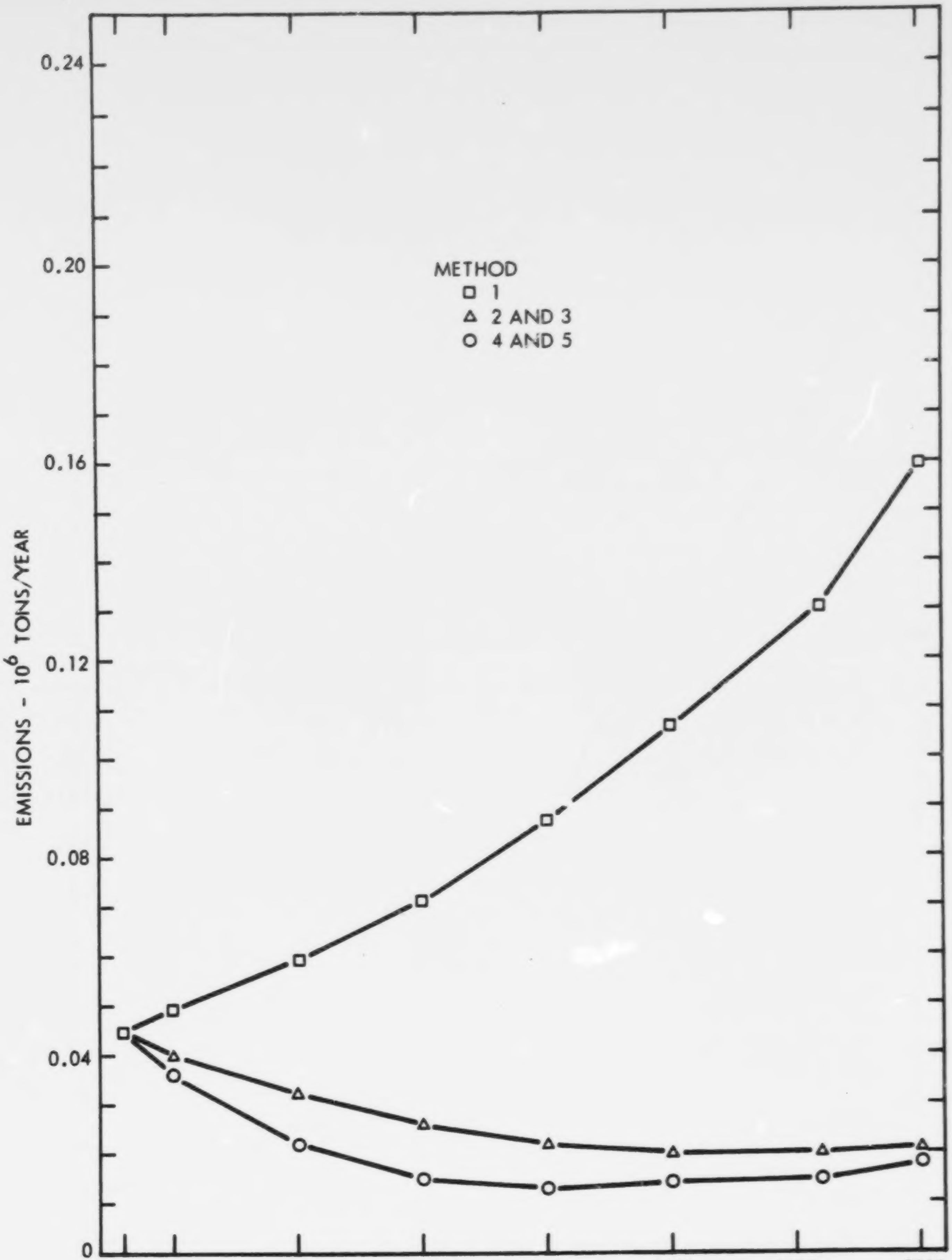

Figure 8.5-26 - Projections of Particulate Emissions - Petroleum

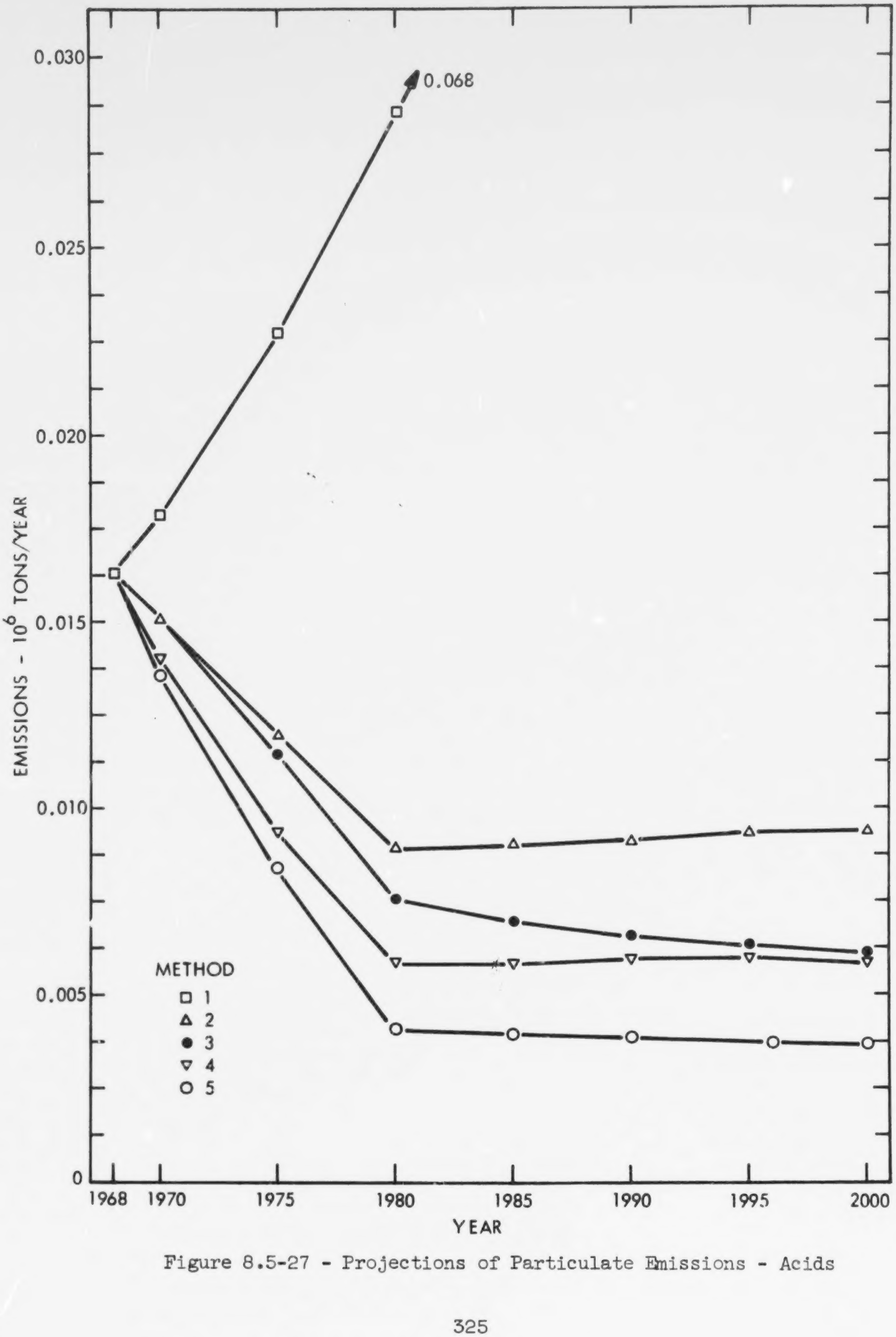

Figure 8.5-27 - Projections of Particulate Emissions - Acids

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9. R & D PLANS

The objective of this phase of the project was to develop a 5-year research and development program which would fill in gaps in knowledge about: particulate sources; effluent stream properties which affect control techniques; control technology; and other aspects or effects of particulate air pollution and its control. The R&D program has been based on two assumed levels of support: Plan A, $5,000,000; and Plan B, $1,000,000. The development of the R&D plans involved the identification during the present program of significant knowledge gaps, the evaluation of the needs for new information, considerations of the probability and degree of success which might be attained, and estimates of the time and costs involved for each proposed research area or task.

9.1 Identification of Major Problems Requiring R&D

Several significant sources were noted for which information was limited or incomplete. The largest of these in terms of tonnage of particulate emitted (and, in fact, one of the largest of all sources) is the crushed stone industry which involves various aspects of quarrying, crushing, grinding and using stone products. The second most significant source for which more data are needed centers around agricultural products and, in particular, on grain elevators, flour and feed mills, cereal manufacture and associated transfer, transportation or handling facilities. Better data are also needed for a number of other agricultural-related sources such as alfalfa dehydration, spraying, and fertilizing operations. The clay and ceramics industry is a third source group which is in much need of study in terms of both total emissions and constituents such as fluorides. In addition to these three most important sources, several other sources exist for which more information is needed. These include: fertilizers other than phosphate; a group which we shall call the miscellaneous chemicals industry (which includes a number of irregular or periodic sources resulting from occasional production runs on specialty chemicals and from start-up or shutdown operations); paint and varnish manufacture, handling and use (including hydrocarbon emissions); iron and steel mills as a source of fluorides; nonmetallic minerals industries (including asbestos, abrasive, etc.); and land clearance operations (including burning, demolition, urban renewal, etc.). Finally, the general area of sources of secondary particulates (those formed in the atmosphere by reactions of gaseous emissions) requires further study to identify the sources and their interrelationships.

Knowledge gaps exist in many aspects of the analysis of particulates. These include the development and standardization of sampling and monitoring techniques and the instrumentation of these operations; the determination of the chemical compositions of the collected dusts from various

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sources and evaluation of its economic values; the determination of the compositions of emitted particulates; and the development of emission standards based on chemical composition as well as on a weight basis. Collection and dissemination of experimental data in all of the above areas should be improved and a stack sampling information center (with computerized storage, retrieval and correlation capabilities) is particularly recommended.

Areas of control technology for which further information is needed include some specific, widely-used types of operations, such as emissions from conveying and handling of materials, and a number of difficult-to-control, fugitive, or small industry sources. The area of materials handling operations is a very significant source on an overall basis since it contributes to particulate emissions from nearly every industrial category. Surprisingly little definitive data on these emissions exists, however, and a systematic research study is imperative. In addition, better control techniques should be developed for several sources such as fertilizers, the primary aluminum industry, the miscellaneous chemicals operations, coke ovens, sinter plants, agricultural product-related sources, etc. The chemical and physical processes involved in the operation of different types of control devices, the effects of pollutant properties and concentrations on efficiencies of various devices, and the advantages and limitations of certain devices in various industries all need to be studied and defined. New approaches will probably be required for the development of control techniques for some sources which are uncontrolled or poorly controlled at present. A development and testing program will be needed to do this. Control methods will need to be evaluated for sources of emissions which give secondary particulate, when these have been identified.

The control of small particle emission requires much improvement, but a general study of small particle technology will be required because of present limitations in control capabilities in this area. Particularly troublesome are sources which emit a fine particulate at low grain loading, but with a high volume of a high temperature carrier gas. (Metallurgical process, such as zinc retorts, aluminum cells, ferroalloys, etc., are examples which present this formidable control problem). The small particle technology studies should include an evaluation of the present state of the problem of fine particle emissions (from all sources) and the present state of control capabilities and limitations for various types of sources. Studies are needed of the growth, agglomeration and collection of small particles to increase the understanding of these processes, so that new improvements or approaches can be made in control technology. New applications and modifications of existing methods and the development of new methods for small particle control will require design, development and testing programs.

The control of combustion sources has already received an enormous amount of attention, but because these sources constitute such a major part of the particulate problem, continuing studies are demanded. The control of emissions from coal combustion is the central problem and requires further studies of: control techniques for electric utility and industrial boilers; new boiler design, operating methods, and combustion techniques; additives which improve collector efficiency; the interrelationship of particulate and SO_2 control; and methods of coal desulfurization. Control of emissions from oil combustion may become increasingly important, as many of the users of coal switch to oil of various grades and possibly in time to synthetic oils derived from coal liquification or solid waste pyrolysis. Control of the emissions from incineration and burning of other combustibles will probably remain a problem needing study.

The detrimental and economic effects of present and projected particulate pollutant levels on health, vegetation, materials, etc. will require continuing evaluation. The interrelationships of the distribution of sources and these receptors and the economic effects of relocation of industries because of pollution-related reasons need to be established. The economic effects on industry of the need to purchase new control equipment to meet more and more stringent emission standards will need evaluation, especially for small industries or small-difficult-to-control sources, where the cost of control equipment may be nearly as large as the value of the plant installation. Allowable emission levels may require further definition in such cases. The economics and economic effects of an increasing use of oils to replace coal and of the transformation of coal to gas or oil need further elucidation.

9.2 Ordering of Priorities and Allocation of Resources

Particulate pollution problems whose solutions will require intensive research and development effort are readily identifiable. An extensive R&D program will require more than the $5 million stipulated as the maximum level to be considered in the development of the present 5-year plans. The major and most urgent problems identified in Section 9.1 can, however, each receive a significant degree of attention within this framework. For the smaller $1 million level of effort all but the most urgent R&D programs must be eliminated and some of these would operate at reduced levels, or be delayed one or more years. Several factors were considered in determining the priority of problems and their support levels: size of the particulate burden involved; the degree to which reliable data are lacking; currently existing programs designed to solve the problem; special characteristics which make the problem important (e.g., small particle sizes, toxic or carcinogenic emissions, analytical difficulties, etc.); the improvement in efficiency of control which might be attained or the probability of successfully completing an R&D program designed to solve the problem; the time and cost involved in the proposed R&D programs; and the total level of support available. Overall, an attempt was made to select R&D programs designed to give results which (when added to the present state of knowledge) would provide the most help in reducing the national particulate problem in the shortest time.

9.2.1 Plan A - $5 Million Level

Once the research and development needs were listed, time schedules were outlined on the basis of urgency of the need for solutions to problems and with the intent of maximizing the flow of information, i.e. so that results of one program could be used advantageously on subsequent programs. Time and cost allotments were then assigned (on the basis of the priorities listed above) for a five year program at the $5 million level. Final adjustments were then made in order to maintain expenditure at a constant $1 million per year.

The total R&D plan is divided into three general areas:

Area I - Programs on Particulate Sources and Analysis
Area II - Programs Related to Control Technology
Area III - Programs on Effects of Particulate Pollutants and Their Control

Within each area of interest several programs concerning a central topic are designated and each program may have one or more years to complete. Programs in Area I are designated by PS (particulate sources), programs in Area II by CT (control technology) and programs in Area III by E (effects). Thus a task designated as CT-1.2 entitled "Laboratory and field studies of emissions and their control during materials handling by conveyers and related equipment" would be a part of the program CT-1, "Extend and Improve Control Technology for Industrial Emissions from Non-Combustion Sources." In this instance the task CT-1.2 would require a contract for a one year study, and is recommended for the first year of the five-year period, because the results should be applicable to a large number of sources.

The program designations, the descriptions of programs and tasks, and the time schedule and allotment for the accomplishment of various objectives of each task are shown in Table 9.1. The total costs of each task, program and area, and the totals by year are shown in Table 9.2. The control technology area will receive the largest portion of funds, 52%, followed by the particulate sources area, 30%, and the effects area, 18%. The expenditure in Areas I and II are highest in the first year and decrease thereafter, emphasizing the urgent need for information which will influence the approach to control technology. The expenditures for the latter area increase steadily from the first through the fifth year, reflecting particularly the increase in programs involving testing of devices. In all, eight programs having 27 tasks are designated in Area I, three programs and 15 tasks in Area II, and four programs with 9 tasks are designated in Area III.

9.2.2 Plan B - $1 Million Level

The development of the $1 million level R&D plan required a further selection of programs listed in the $5 million level plan. At this lower level of support, only three of the eight Area I programs and three of the four Area III programs could be included. Most of the programs which were included were necessarily assigned lower levels of support and, in addition, certain tasks had to be omitted or delayed.

For programs and tasks which are included in Plan B, the designations remain the same as in Plan A and are listed in Table 9.1. The time schedule, time and cost allotments, and the task, program, area and yearly totals are shown in Table 9.2. The program and task costs were adjusted to a constant expenditure of $200,000 per year. Again the area of control technology receives the largest portion of support, 59%, while the particulate sources studies receives 34%, and the two effects programs only 7%.

The proposed R&D plans can be modified to include, for example, other or newly identified tasks of high priority, or exceptionally meritorious ideas received as unsolicited proposals. In its present form it will provide the framework within which answers can be developed to some of our more urgent problems concerning the identification, effects and control of particulate emissions.

TABLE 9.1

FIVE-YEAR R&D PROGRAM DESCRIPTIONS ON PARTICULATE POLLUTANTS
($5 Million Level)

Area I - Programs on Particulate Sources and Analysis

Program Designation	Program Year 1	2	3	4	5
PS-1	Crushed Stone Industry -1.1 Identify and evaluate sources - Collect and evaluate available data - Identify all sources, including difficult-to-control and fugitive sources - Measure emission rates	-1.2 Determine chemical composition and physical properties of particulates from important sources - Properties pertinent to control technology - Particle size, density, etc. - Evaluate probable gas flow rates and grain loadings			
PS-2	Agricultural Products and Related Industries -2.1 Grain elevators and associated handling operations - Collect and evaluate available data - Measure emission rates -2.2 Flour and feed mill operations - Determine emissions	-2.3 Other grain products - Determine emissions from cereal manufacture, brewery operations, etc.	-2.4 Determine chemical and physical properties of particulates from grain and related operations	-2.5 Evaluate other agricultural sources; measure emissions and analyze particulates as necessary	→
PS-3	Clay and Ceramics Industries		-3.1 Identify sources, collect available data; determine emission rates	-3.2 Determine chemical compositions and physical properties of particulates	
PS-4	Miscellaneous Sources -4.1 Fertilizers other than phosphates - Identify all sources - Collect and evaluate available data	-4.2 Miscellaneous chemicals industries - Identify irregular or periodic sources	-4.3 Paint and varnish manufacture and use - Identify all sources and determine emissions	-4.4 Miscellaneous sources - (Iron and steel (fluoride emissions) - Land clearance, etc. - Nonmetallic minerals (asbestos, abrasives, etc.)	-4.5 Miscellaneous sources - Identify other probably significant sources for which data are very limited - Surveys of sources
PS-5	Stack Sampling Information Center -5.1 Set up computer-based information storage and retrieval system - Collect and encode available data - Perform pilot searches - Arrange for collection of current data	-5.2 Operation of information center - Collect and enter new data - Perform routine searches and correlations - Pinpoint trends and emerging problems - Note geographical relationship of problems, etc.	→	→	→

Program Designation	1	2	3	4	5
CT-2	Small Particle Technology -2.1 Evaluate scope of small particle pollutant problem - Evaluate present particulate collection methods in terms of small particle efficiency - Identify industries where small particle emissions are worst	-2.2 Study mechanics of agglomeration and collection -2.3 Evaluate potential methods for improving small particle collection efficiency - New applications for fabric filters - New control methods	→ → - Laboratory test proposed new applications and new methods such as sonic, ultrasonic or supersonic devices, pulsed ESPs, series devices, etc.	→ → - Continue testing program	→ - Field test recommended - Control methods on selected sources
CT-3	Control of Combustion Sources -3.1 Control of emissions from coal combustion - Studies of control techniques and emission standards for electric utilities - Studies for industries using coal-fired boilers - Interrelationship of particulate and SO_2 control	→	-3.2 Modification of coal-combustion processes - Studies of coal-fired boiler design and operating parameters in relation to emission levels, - Studies of additives which improve collector efficiency - Studies of new methods of combusting coal	→ - Define operating parameters required to optimize collection efficiencies by different control devices -3.3 Develop improved or novel furnace and boiler designs, integrated with collection and control devices	→ - Test new operating parameters - Test new approaches and designs -3.4 Studies of coal desulfurization
	-3.5 Control of emissions from incineration, etc. - Municipal - Commercial - Apartments - Residential	-3.6 Control of Emissions from other controlled fires - Slash and bark burning - Prescribed fires	-3.7 Control of emissions from oil combustion - Identify pollutants requiring control ex. acids, carcinogens, vanadium, etc. - Evaluate growth of oil combustion resulting from new particulate and SO_2 emission standards	→ - Evaluate control techniques for oil combustion - Optimize boiler design and operating parameters	→ - Develop emission standards for pollutants from oil combustion - Study emissions from combustion of synthetic oils from solid waste pyrolysis, coal liquefaction, etc.

Area III - Programs on Effects of Particulate Pollutants and Their Control

E-1	Economic Effects of Control Costs on U.S. Industry -1.1 Evaluate costs of control equipment for each type of industry - Compare costs for added control equipment in series vs. new equipment - Compare costs in terms of emission standards	→ - Continue evaluation and include - Study control costs for fugitive sources and small industries	→ - Refine cost evaluations for proposed future emission standards - Develop criteria for using the ratio of the cost of the required control devices to the plant installation value as an aid in setting allowable emission levels	→ - Define optimum control levels for various industries as a function of cost and emission levels -1.2 Evaluate economic effects produced by conversion from coal to oil and gas as a result of new standards	-1.3 Evaluate economics of synthetic oils from solid waste disposal; of coal gasification vs. scrubbing systems, etc.

Program Designation	Program Year 1	2	3	4	5
PS-6	**Sampling and Monitoring Techniques** -6.1 Evaluation of Methods - Laboratory and field testing procedures for selected sources - In situ measurements - Methods for source identification from atmospheric measurements	-6.2 Chemical composition analysis - Improve methods - Develop methods for more elements and compounds	-6.3 Instrumentation - Develop instrumentation for additional analyses - Improve remote sampling and monitoring techniques - Computerization	→ data	-6.4 Standardize all sampling and data reduction techniques
PS-7	**Chemical Compositions of Collected and Emitted Dusts** -7.1 Chemical analysis of collected dusts; chemical analysis of emissions from selected sources; variation of composition with particle size	→ -7.2 Compilation of chemical composition data; assessment of potential economic value; dissemination of data	-7.3 Evaluate new separation, recovery, and utilization procedures for useful constituents	→	-7.4 Consider emission standards based on chemical analysis of emitted particulate or gaseous sources of secondary particulates
PS-8	**Secondary Particulates** -8.1 Study formation of secondary particulates from gaseous emissions - Identify sources of gases - Identify precursors of particulates	-8.2 Atmospheric chemistry and physics - Identify reactions leading to particulates - Study formation and deposition rates of particulates	-8.3 Evaluate particulate levels produced by secondary reactions		

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Area II - Programs Related to Control Technology

Program Designation	1	2	3	4	5
CT-1	**Extend and Improve Control Technology for Industrial Emissions from Non-Combustion Sources** -1.1 Studies of operating principles of existing control equipment - Studies of chemical and physical processes involved in control operations - Studies of the effect of pollutant properties and concentration on efficiency - Define limitations of various types of equipment in terms of particulate properties, industry, etc. -1.2 Laboratory and field studies of emissions and their control during materials handling by conveyors, and related equipment	-1.3 Studies of applicability of existing equipment to poorly controlled sources - Fugitive sources - Difficult-to-control sources - Small industries	→ - Fertilizers - Primary aluminum - Miscellaneous chemical industry (non-continuous sources)	→ - Coke ovens - Sinter plants - Agricultural sources - Studies of industries using process coal	→ - other particulate sources
	→	-1.4 New approaches to control of specific or general sources - Ex. turbulent contact absorbers	→ - Continue development programs - Laboratory testing of new methods	→ - Continue testing program	→ - Field test recommended control methods - Project future emission levels using new controls -1.5 Evaluate control methods for emissions which give secondary small particles

Program Designation	Program Year 1	2	3	4	5
E-2	**Economic Effects of Particulate Pollution on the Public and Industry** -2.1 Evaluation of problems - Develop particulate source distribution maps in relation to geography, population, materials and agricultural products - Evaluate economic effects of relocation of selected industries because of pollution-related reasons	→ - Effects on materials - Agricultural products - Effect of air pollution on property values	→ - Review and evaluation of health costs from particulate pollutants		
E-3	**Toxicological Effects** -3.1 Evaluate scope of toxicological problems from particulate emissions - Review toxic effects on man - Review toxic effects on animals - Review toxic effects on plants - Collect emissions data on toxic pollutant components	→ - Identify most toxicologically significant components in particulate emissions - Identify toxicity factors from secondary particulates - Determine particle size relationships of toxic pollutant components	-3.2 Toxicological studies of particulate pollutants from selected sources	→	-3.3 Use toxicity data to help set emission standards
E-4	**Fundamental Studies on Particulates** -4.1 Studies of formation and properties of particulates - Formation in various sources - Properties as a function of composition			-4.2 Studies on effects of particulates - Define particle size influence on atmospheric effects, reactions, etc. - Study mechanisms of natural particulate removal processes - Determine fate of small particle emissions	

TABLE 9.2

FIVE-YEAR R&D PROGRAM COSTS ON PARTICULATE POLLUTANTS

Plan A. $5 Million Level of Support

Program Designation	Task Designation	Program Year 1	2	3	4	5	Task Totals	Program Totals
Programs on Particulate Sources and Analysis								
PS-1 Crushed Stone	PS-1.1	50,000					50,000	
	PS-1.2		50,000				50,000	100,000
PS-2 Agricultural & Related Products	PS-2.1	50,000					50,000	
	PS-2.2	40,000					40,000	
	PS-2.3		40,000				40,000	
	PS-2.4			50,000			50,000	
	PS-2.5				40,000	40,000	80,000	260,000
PS-3 Clay & Ceramics	PS-3.1			40,000			40,000	
	PS-3.2				40,000		40,000	80,000
PS-4 Miscellaneous Sources	PS-4.1	50,000					50,000	
	PS-4.2		50,000				50,000	
	PS-4.3			40,000			40,000	
	PS-4.4				40,000		40,000	
	PS-4.5					40,000	40,000	220,000
PS-5 Information Center	PS-5.1	40,000					40,000	
	PS-5.2		30,000	30,000	30,000	30,000	120,000	160,000
PS-6 Sampling & Monitoring	PS-6.1	50,000					50,000	
	PS-6.2		50,000				50,000	
	PS-6.3			75,000	75,000		150,000	
	PS-6.4					75,000	75,000	325,000
PS-7 Chemical Compositions	PS-7.1	40,000	35,000				75,000	
	PS-7.2		40,000				40,000	
	PS-7.3			45,000	45,000		90,000	
	PS-7.4					40,000	40,000	245,000
PS-8 Secondary Particulates	PS-8.1	35,000					35,000	
	PS-8.2		35,000				35,000	
	PS-8.3			40,000			40,000	110,000
Research Area I Totals		355,000	330,000	320,000	270,000	225,000		$1,500,000
Programs on Control Technology								
CT-1 Industrial, Non-Combustion Sources	CT-1.1	100,000					100,000	
	CT-1.2	50,000					50,000	
	CT-1.3		100,000	75,000	75,000	75,000	325,000	
	CT-1.4		75,000	100,000	100,000	100,000	375,000	
	CT-1.5					100,000	100,000	950,000
CT-2 Small Particle Technology	CT-2.1	70,000					70,000	
	CT-2.2		50,000	75,000	50,000		175,000	
	CT-2.3		100,000	75,000	75,000	100,000	350,000	595,000
CT-3 Combustion Sources	CT-3.1	100,000	80,000				180,000	
	CT-3.2			125,000	100,000	100,000	325,000	
	CT-3.3				100,000	50,000	150,000	
	CT-3.4					75,000	75,000	
	CT-3.5	100,000					100,000	
	CT-3.6		75,000				75,000	
	CT-3.7			50,000	50,000	50,000	150,000	1,055,000
Research Area II Totals		420,000	480,000	500,000	550,000	650,000		2,600,000

TABLE 9.2 (Concluded)

Plan A. $5 Million Level (Concluded)

Program Designation	Task Designation	Program Year 1	2	3	4	5	Task Totals	Program Totals
Programs on Effects								
E-1 Effects of Control Costs	E-1.1	50,000	40,000	40,000	40,000		170,000	
	E-1.2				40,000		40,000	
	E-1.3					50,000	50,000	260,000
E-2 Effects of Pollutants	E-2.1	75,000	90,000	70,000			225,000	235,000
E-3 Toxicological Effects	E-3.1	50,000	60,000				110,000	
	E-3.2			70,000	50,000		120,000	
	E-3.3					75,000	75,000	305,000
E-4 Fundamental Studies	E-4.1	50,000					50,000	
	E-4.2				50,000		50,000	100,000
Research Area III Totals		225,000	190,000	180,000	180,000	125,000		900,000
Totals, All Programs		1,000,000	1,000,000	1,000,000	1,000,000	1,000,000		5,000,000

Plan B. $1 Million Level of Support

PS-1 Crushed Stone	PS-1.1	50,000					50,000	
	PS-1.2		50,000				50,000	100,000
PS-2 Agricultural & Related Products	PS-2.1		45,000				45,000	
	PS-2.2			40,000			40,000	
	PS-2.3				35,000		35,000	
	PS-2.4					40,000	40,000	160,000
PS-3 Clay & Ceramics	PS-3.1			40,000			40,000	
	PS-3.2				40,000		40,000	80,000
Research Area I Totals		50,000	95,000	80,000	75,000	40,000		340,000
CT-1 Industrial, Non-Combustion Sources	CT-1.1	45,000					45,000	
	CT-1.2	35,000					35,000	
	CT-1.3		40,000	35,000	35,000	50,000	160,000	240,000
CT-2 Small Particle Technology	CT-2.1	35,000					35,000	
	CT-2.2		30,000				30,000	
	CT-2.3			45,000	50,000		95,000	160,000
CT-3 Combustion Sources	CT-3.1		35,000				35,000	
	CT-3.2			40,000	40,000	75,000	155,000	190,000
Research Area II Totals		115,000	105,000	120,000	125,000	125,000		590,000
E-1 Effects of Control Costs	E-1.1	35,000					35,000	
E-2 Effects of Pollutants	E-2.1					35,000	35,000	
Research Area III Totals		35,000				35,000		70,000
Totals, All Programs		200,000	200,000	200,000	200,000	200,000		1,000,000

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APPENDIX A

POLLUTION DOCUMENT RETRIEVAL SYSTEM

The various phases of the Pollution Document Retrieval system as outlined in the accompanying system flowchart (Figure A-1) will accomplish the following:

1. Establish a "Master Keyword File" from the "Microthesaurus of Air Pollution Terms" published by the U.S. Department of HEW. This Master Keyword File will contain each Keyword in the Thesaurus, its associated code and a computer-generated index which will be used in the search.

2. Establish a "Master Document File" which will contain all relevant documents. The record for each document will contain full bibliographic information plus all keywords which are descriptive of the information contained in the article. Keywords may be from the Microthesaurus list only.

3. Add the SIC codes associated with each document to the Master Document File as this information was not available at the time the document cards were produced.

4. Provide the ability to delete any documents from the master file. To add new documents to the master file, the new documents must first be created in the same way that the master file was created, then merged with the master file.

5. Provide the ability to order and list the Master Document File according to the following criteria: Accession Number, SIC code, Author and/or Agency.

6. Provide a search facility by which the Master Document File may be searched for documents which contain specific information. The search criteria can be any combination of the following: Accession Number, SIC code, Author and/or Keyword(s). Keywords may be inclusive, exclusive or alternative. The search program will then list all documents which conform to the criteria specified.

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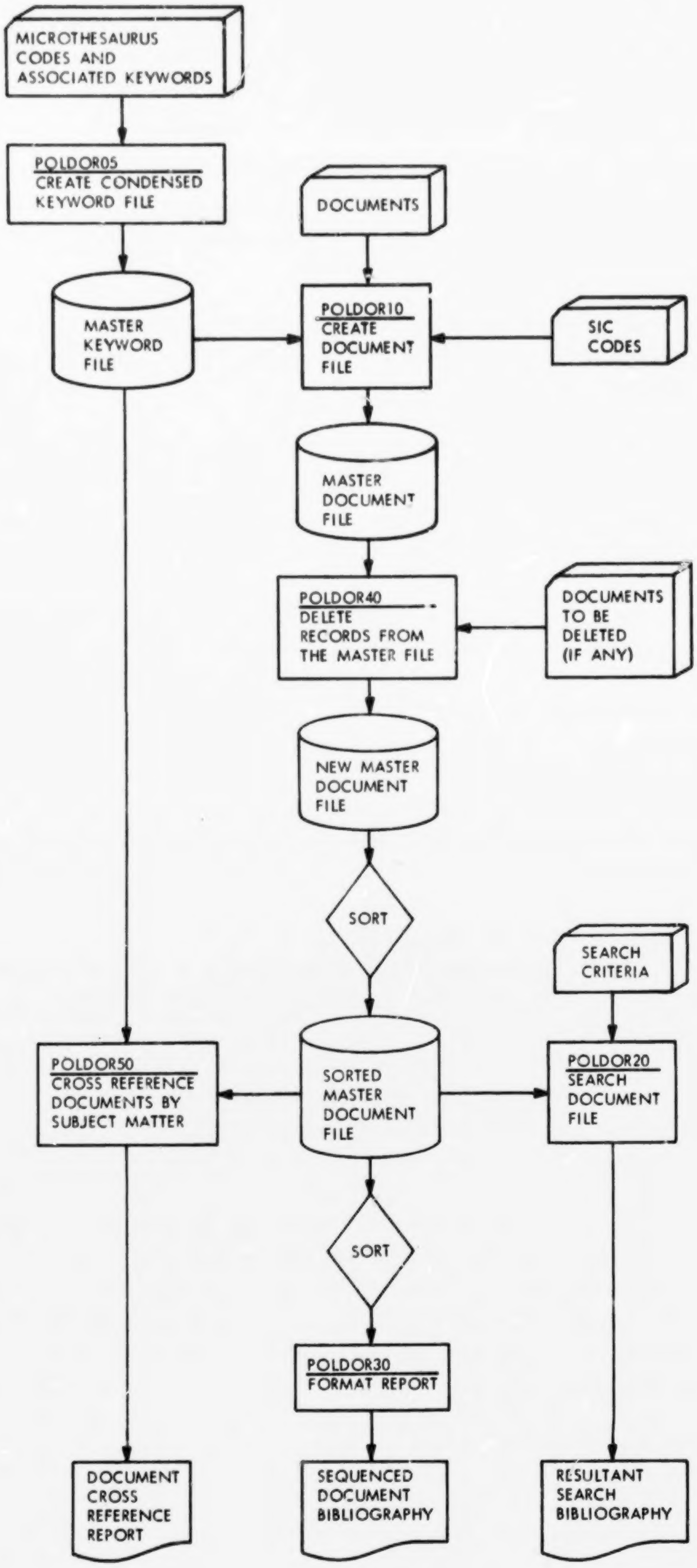
MICROTHESAURUS CODES AND ASSOCIATED KEYWORDS
POLDOR05
CREATE CONDENSED KEYWORD FILE
DOCUMENTS
MASTER KEYWORD FILE
POLDOR10
CREATE DOCUMENT FILE
SIC CODES
MASTER DOCUMENT FILE
POLDOR40
DELETE RECORDS FROM THE MASTER FILE
DOCUMENTS TO BE DELETED (IF ANY)
NEW MASTER DOCUMENT FILE
SORT
SEARCH CRITERIA
POLDOR50
CROSS REFERENCE DOCUMENTS BY SUBJECT MATTER
SORTED MASTER DOCUMENT FILE
POLDOR20
SEARCH DOCUMENT FILE
SORT
POLDOR30
FORMAT REPORT
DOCUMENT CROSS REFERENCE REPORT
SEQUENCED DOCUMENT BIBLIOGRAPHY
RESULTANT SEARCH BIBLIOGRAPHY

Examples of Search Criteria

Following are examples of possible searches:

a) All documents written by William O. Jenkins pertaining to Sampling Methods, Measurement Methods and Particulates.

b) All documents with an SIC code of 9110 but that pertain to neither Sulphur Oxides nor Carbon Monoxide.

c) All documents with an SIC code of 9110, written by William O. Jenkins and pertaining to Stacks or Scrubbers of Hydrocarbons.

d) The document with accession number A1811. (Since accession numbers are unique for each document, only one such document will be printed.)

e) All documents written by William O. Jenkins.

f) All documents pertaining to Smog.

7. Provide a cross reference listing of all documents by subject matter. The subjects must be from the microthesaurus list only.

BRIEF RESUME OF PROGRAMS

1. POLDOR05

PURPOSE: The master keyword file is the required input to create the document file. This program changes the variable word length keyword (subject matter) into a 4 character code word.

INPUT: See Sheet Format No. 4 for input layout. Keywords from Microthesaurus List.

OUTPUT: Master keyword file sorted by ascending accession number.

2. POLDOR10

PURPOSE: Creates master document tape. A utility sort program may be applied to this tape to place document in ascending accession number if desired.

INPUT:
(a) Master keyword file from POLDOR05
(b) SIC codes. See attached card layout Sheet No. 1, 4 of 4 for input format
(c) Document information; see attached card layout sheets Nos. 1, 2, and 3 of 4

OUTPUT: Master document tape composed of unblocked variable length records.

3. POLDOR20

PURPOSE: To search through the master document tape by accession number, author, SIC code(s) and/or subject matter and produce a bibliography of all requested documents.

INPUT:
(a) Master document tape
(b) Search criteria see attached sheet No. 2 - no limit to number of documents in search

OUTPUT: Bibliography of all documents requested.

4. POLDOR30

PURPOSE: To produce a complete bibliography of all documents on the master tape.

INPUT: Master document tape after a utility sort has been used to sequence the documents by author, agency, accession number or SIC code.

OUTPUT: A complete bibliography of all documents on the master document tape.

5. POLDOR40

PURPOSE: A maintenance program for the master document tape to delete entire records by accession number only.

INPUT: Accession numbers of all documents to be deleted. See attached card layout sheet No. 3.

OUTPUT: A list of all documents deleted.

Note: To add records to the master document tape you would create a file using POLDOR10 then sort/merge with the master tape using a utility.

6. POLDOR50

PURPOSE: To create a cross reference listing of all documents in the master document file by subject matter.

INPUT: (a) Master keyword file from POLDOR05
(b) Master document file from POLDOR10

OUTPUT: Cross reference report

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INTERNATIONAL BUSINESS MACHINES CORPORATION

MULTIPLE-CARD LAYOUT FORM

Form X24-6599-0
Printed in U.S.A.

Company Poldor 10
Application Document Card Types 1, 3 by Sheet Format #1 Date ______ Job No. ______ Sheet No. 1 of 4

ACCESSION NUMBER | CD TYPE I | SERIAL | BLANKS | CODE 1 | CODE 2 | CODE 3 | | | | | | | | | | | CODE 14

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

1st card contains 1
subsequent cards (if any)
contain 2 - 9

Codes: 1 or 2 Alpha character plus 2 or 3 digits
left aligned, right fill with blanks
last code followed by $\begin{smallmatrix}0\\8\\2\end{smallmatrix}$ in first column of next code field

99999999999999999999999999999999999999999999999999999999999999999999999999999999
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

Dup. | CD TYPE 3 | SERIAL | AUTHOR ENTRY

one per card
form: Last Name, IƀI $\begin{smallmatrix}0\\8\\2\end{smallmatrix}$

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

1st card contains 1,
subsequent cards (if any) contain 2 - 9

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Note: There is no card type 2

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INTERNATIONAL BUSINESS MACHINES CORPORATION

MULTIPLE-CARD LAYOUT FORM

Form X24-6599-0
Printed in U. S. A.

Company Poldor 10

Application Document Card Types 4,5,6 by Sheet Format #1 Date ____ Job No. ____ Sheet No. 2 of 4

Dup. (1–5)	CD TYPE 4 (6)	SERIAL (7)	AGENCY ENTRY followed by 0 8 2 (8–80)

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1st card contains 1
subsequent cards (if any)
contain 2 - 9

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			DATE		
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Dup. (1–5)	CD TYPE 6 (6)	SERIAL (7)	TITLE ENTRY followed by 0 8 2 (8–80)

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1st card contains 1, subsequent
cards (for long titles), 2 - 9

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MULTIPLE-CARD LAYOUT FORM

Form X24-6599-0
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Company Poldor 10
Application Document Card Types 7 by Sheet Format #1 Date ______ Job No. ______ Sheet No. 3 of 4

Dup.

CD TYPE 7

SERIAL

SOURCE ENTRY followed by

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1st card contains 1
subsequent cards (if any)
contain 2 - 9

9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
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Company Poldor 10
Application SIC Code Input by Sheet Format #1 Date Job No. Sheet No. 4 of 4

ACCESSION NUMBER	SIC CODE 1	SIC CODE 2	
9 9 9 9 9	9 9 9 9	9 9 9 9	9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
1 2 3 4 5	6 7 8 9	10 11 12 13	14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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MULTIPLE-CARD LAYOUT FORM

Form X24 6599 0
Printed in U.S.A.

Company Poldor 20
Application Search Request by Sheet Format #2 Date ______ Job No. ______ Sheet No. 1 of 1

CARD NO. | ACCESSION NO. | SIC CODE | AUTHOR

1

9|99999|9999|9999999999999999999999999999999999999999999999999999999999999999999999
1|2 3 4 5 6|7 8 9 10|11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

└ There must always be a card 1 even if rest of card is blank

└ author must be punched exactly as on document (last name, first initial & middle initial)

99999999999999999999999999999999999999999999999999999999999999999999999999999999
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

CARD NO. 2-9 | (AND) (NOT) (OR) | KEYWORDS one/card; maximum of 8 keywords/search

9|999|9999999999999999999999999999999999999999999999999999999999999999999999999999
1|2 3 4|5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

└ exclusive (NOT), chose (OR), inclusive (AND OR BLANK) combinations are not allowed

if more than 1 keyword,
they follow on cards 3-9

99999999999999999999999999999999999999999999999999999999999999999999999999999999
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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9|9999999999999999999999999999999999999999999999999999999999999999999999999999999
1|2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

└ THIS CARD MUST BE THE LAST CARD IN THE SEARCH DATA DECK

99999999999999999999999999999999999999999999999999999999999999999999999999999999
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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MULTIPLE-CARD LAYOUT FORM

Form X24-6599-0
Printed in U. S. A.

Company Poldor 40
Application Maintenance Program by Sheet Format #3 Date ______ Job No. ______ Sheet No. 1 of 1

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

A or R —Right Justified

INPUT MAXIMUM OF 16 ACCESSION NUMBERS PER CARD. MAXIMUM OF 300 ACCESSION NUMBERS

9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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MULTIPLE-CARD LAYOUT FORM

Form X24-6599-0
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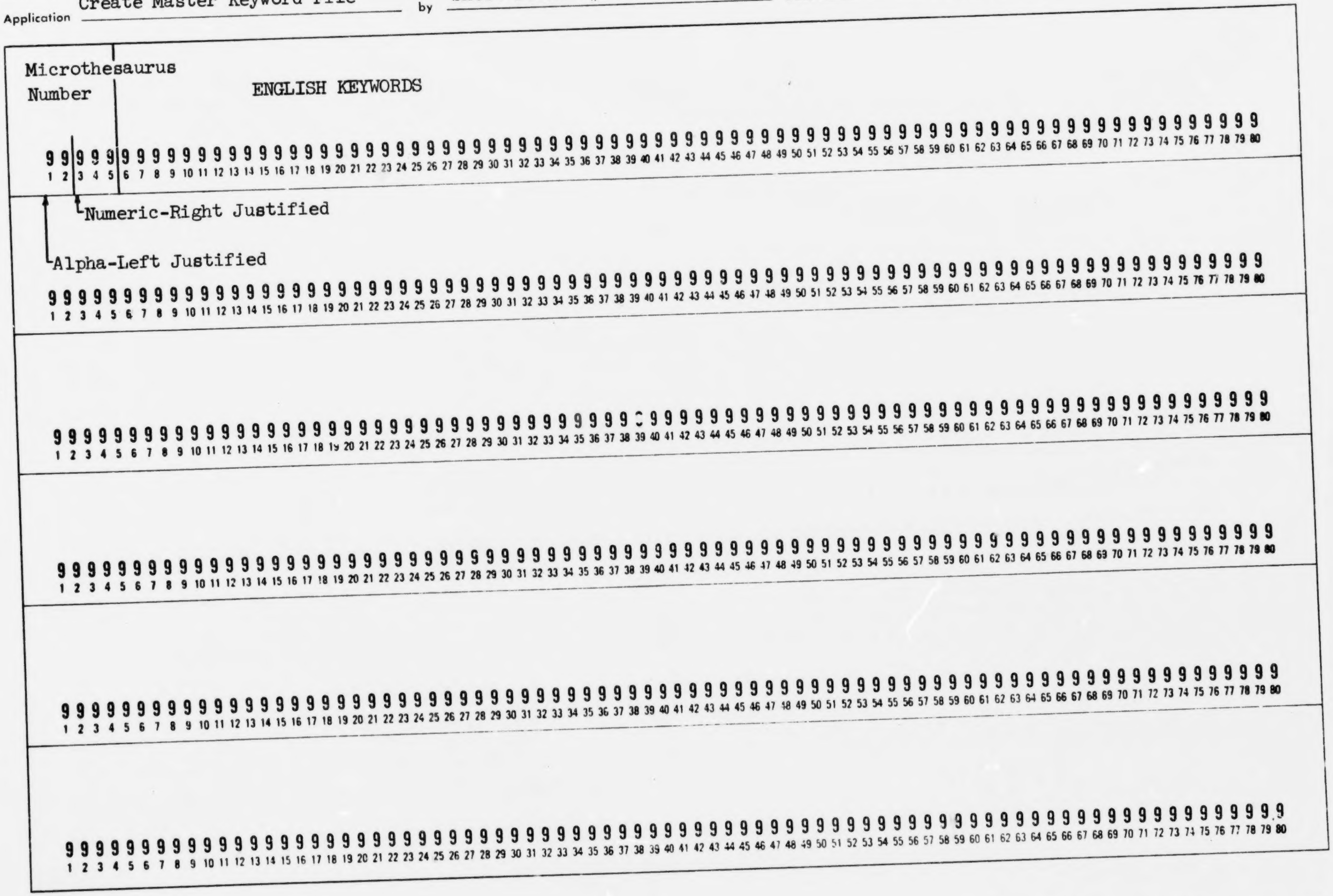
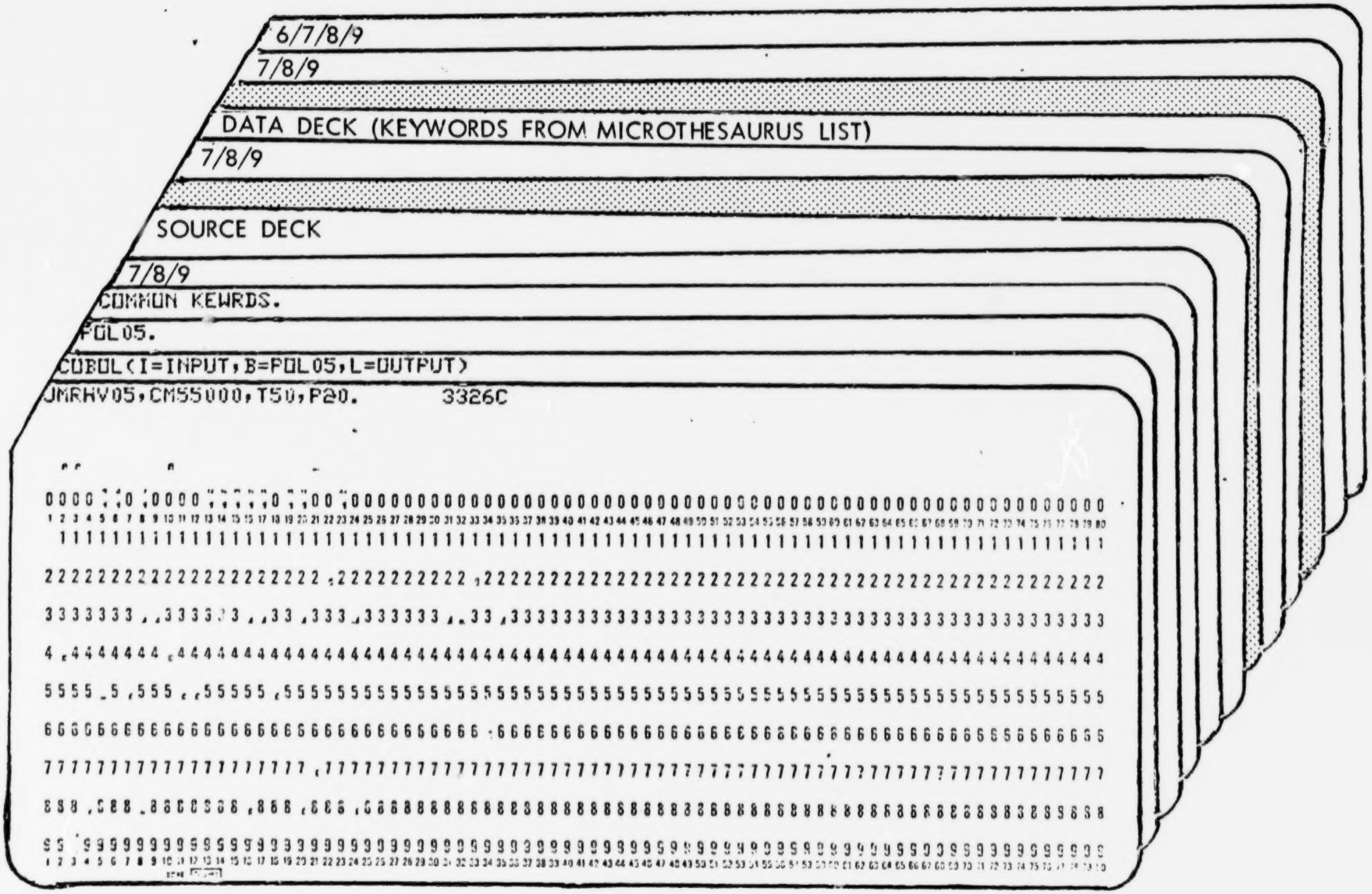
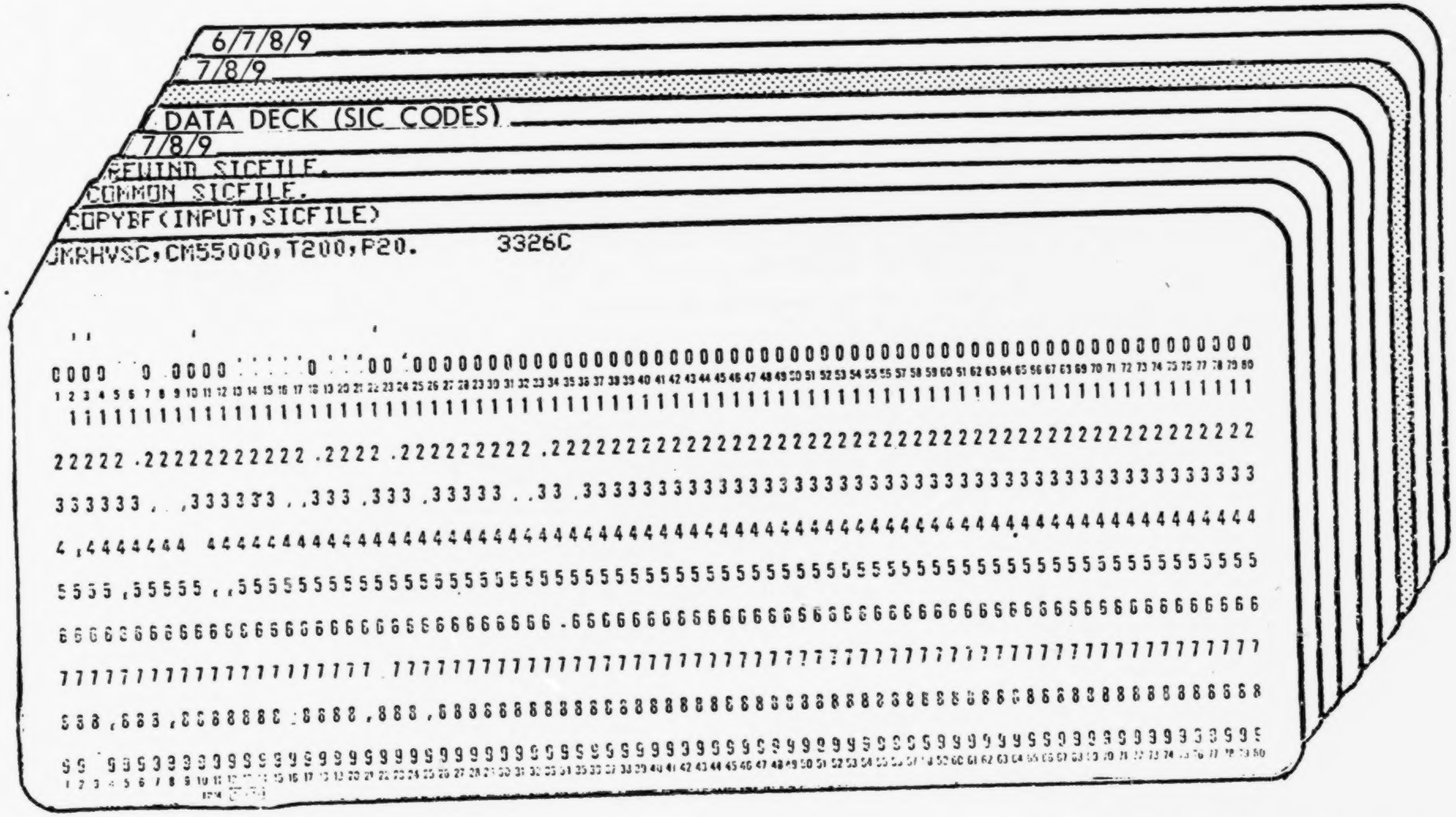
Company Poldor 05
Application Create Master Keyword File
by Sheet Format #4
Date
Job No.
Sheet No. 1 of 1



DECK SET-UP FOR POLDOR05

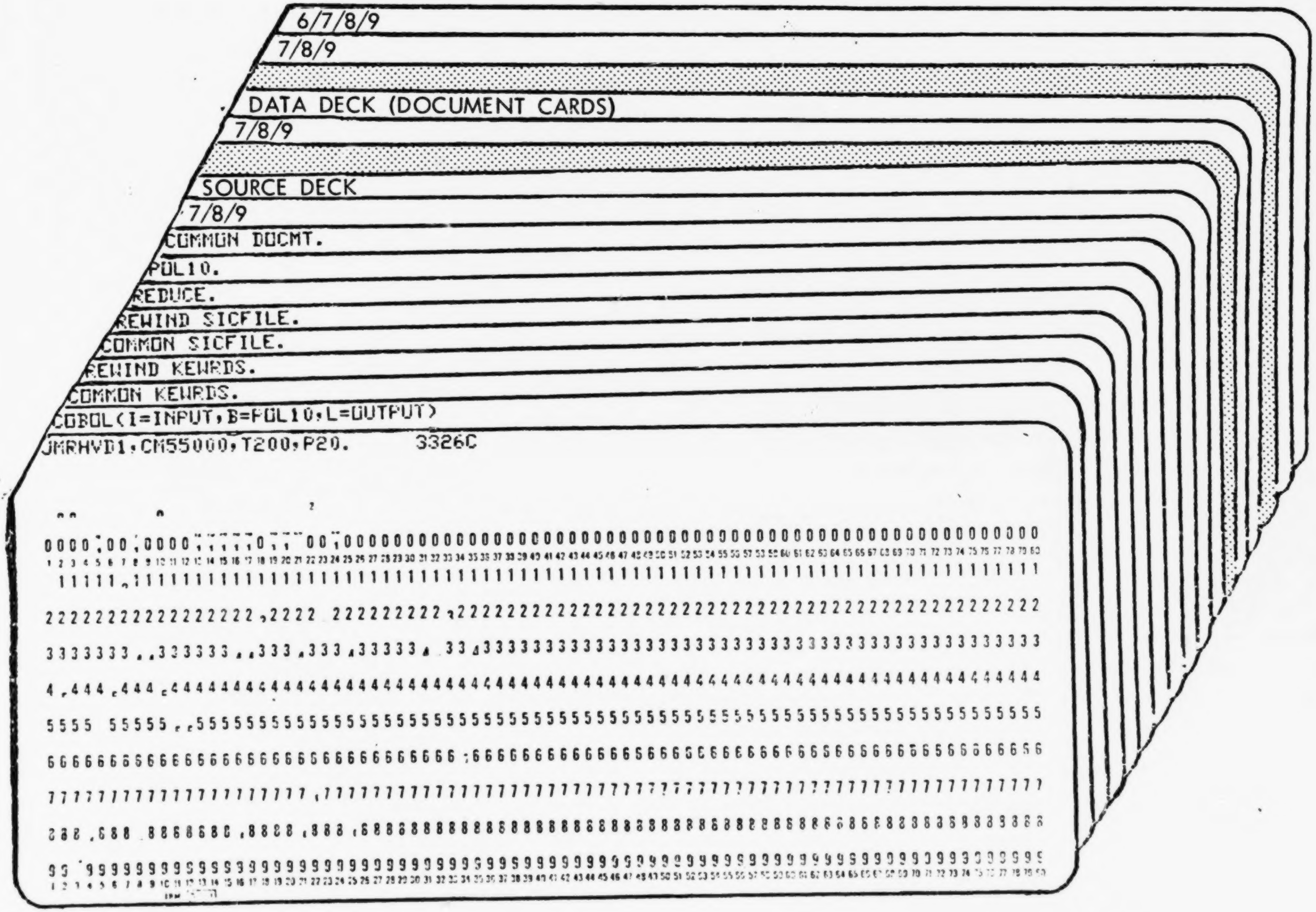

6/7/8/9
7/8/9
DATA DECK (KEYWORDS FROM MICROTHESAURUS LIST)
7/8/9
SOURCE DECK
7/8/9
COMMON KEWRDS.
POL05.
COBOL(I=INPUT,B=POL05,L=OUTPUT)
JMRHV05,CM55000,T50,P20.   3326C

CARD TO DISK

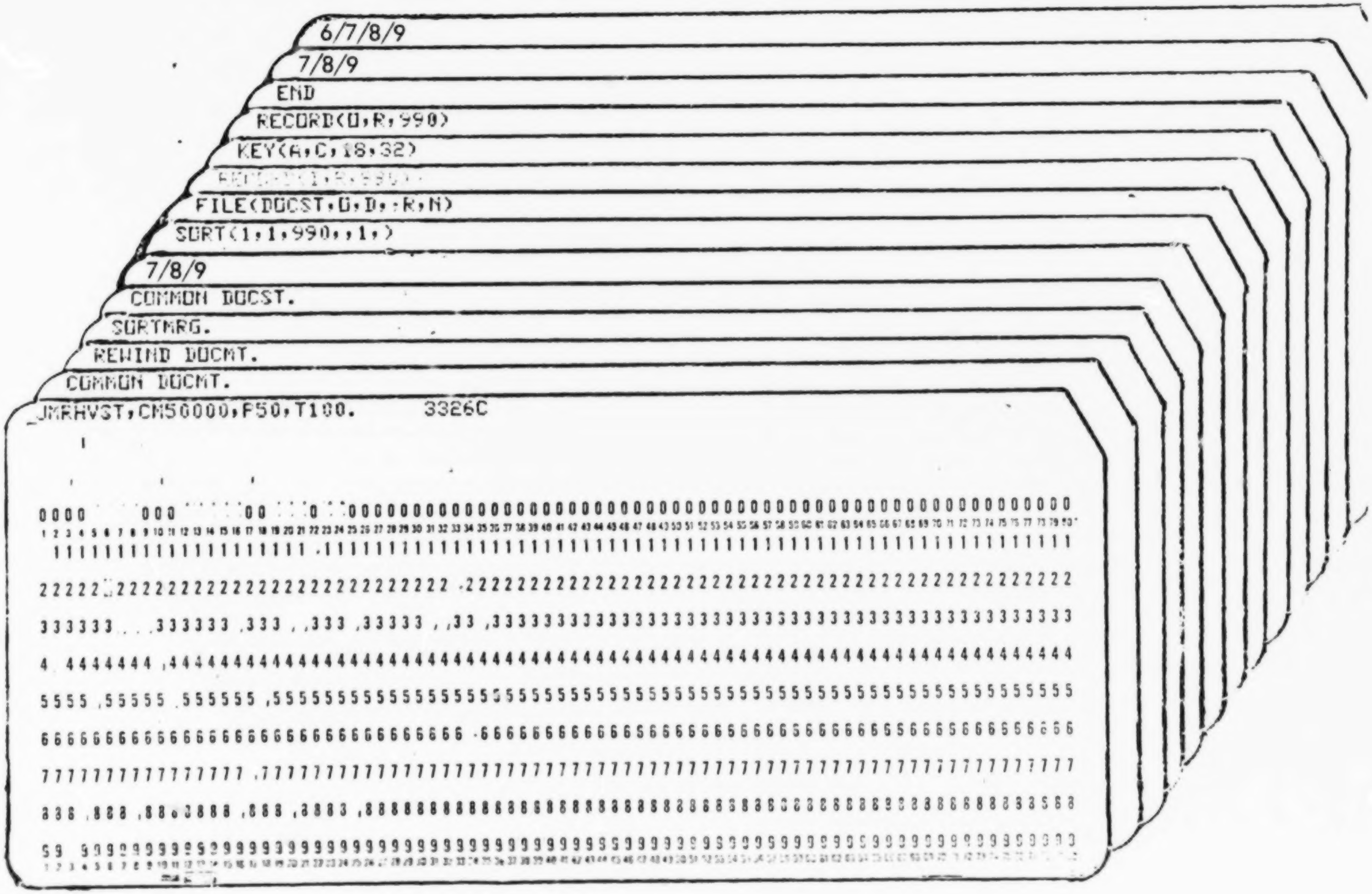


```
6/7/8/9
7/8/9

7/8/9
REWIND SICFILE.
COMMON SICFILE.
COPYBF(INPUT,SICFILE)
JMRHVSC,CM55000,T200,P20.     3326C
```

DECK SET-UP FOR POLDOR10

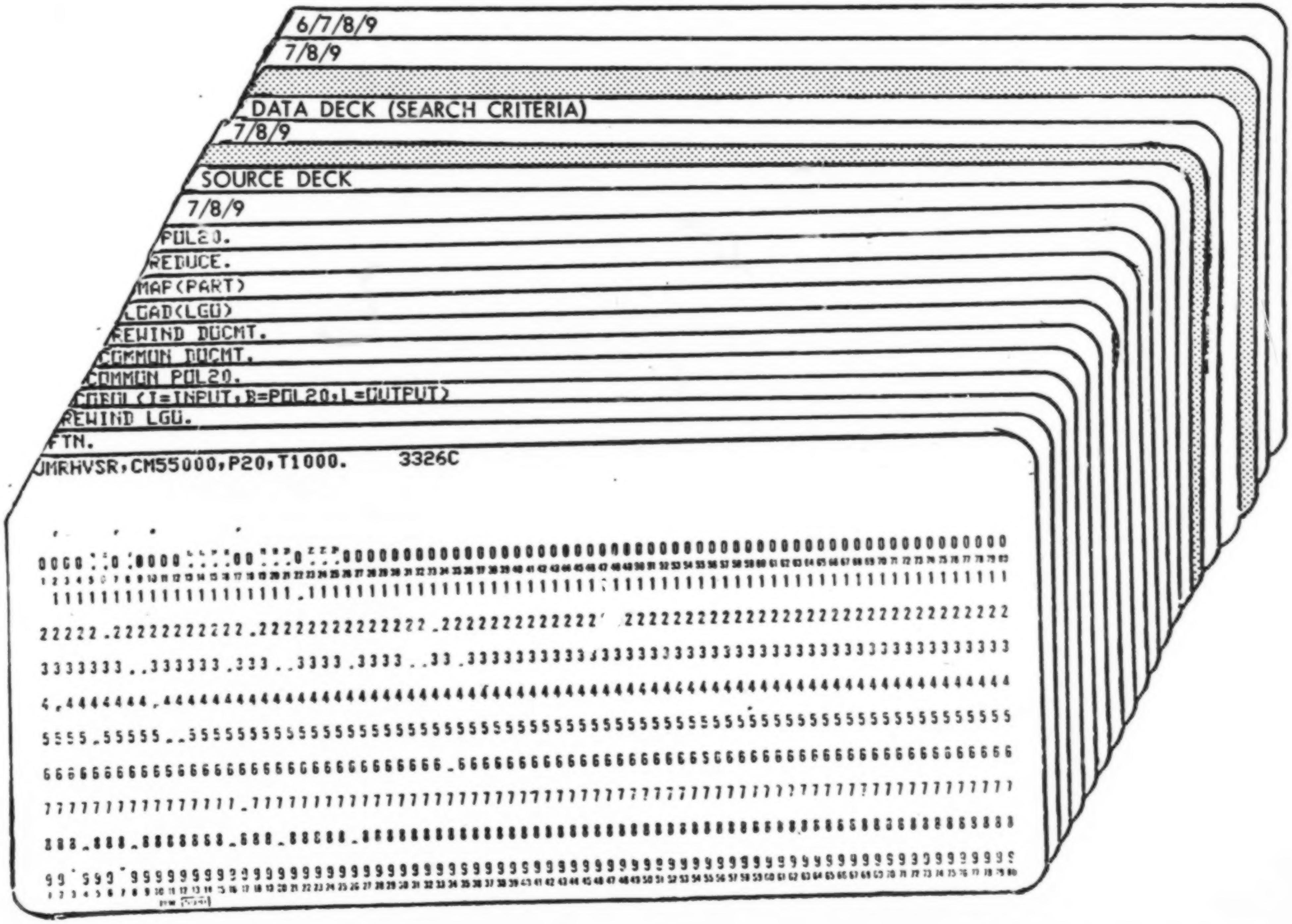


UTILITY SORT-MERGE OF MASTER DOCUMENT TAPE



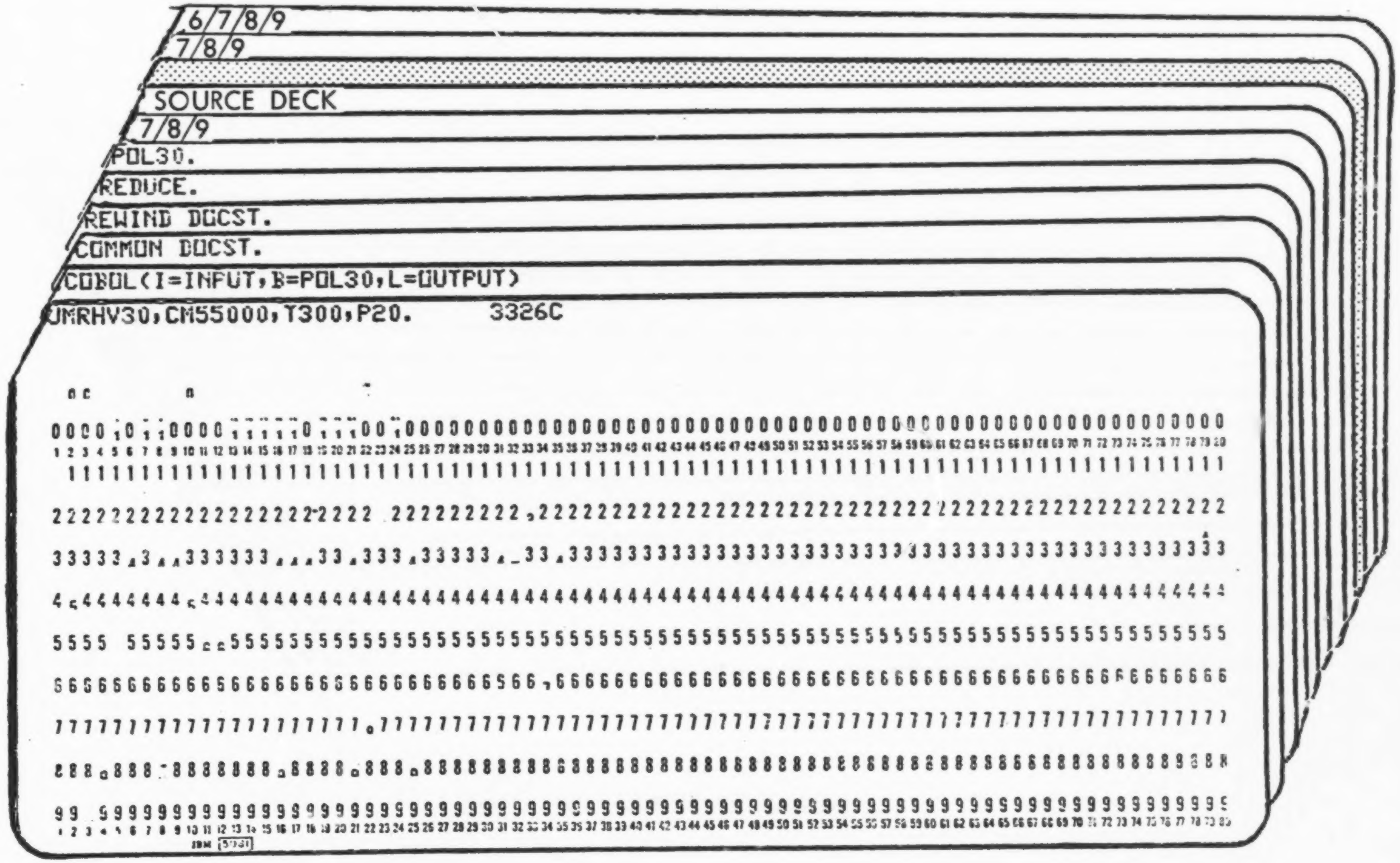
```
6/7/8/9
7/8/9
END
RECORD(D,R,990)
KEY(A,C,18,32)
RECORD(I,R,990)
FILE(DOCST,D,D,,R,N)
SORT(1,1,990,,1,)
7/8/9
COMMON DOCST.
SORTMRG.
REWIND DOCMT.
COMMON DOCMT.
JMRHVST,CM50000,F50,T100.     3326C
```

DECK SET-UP FOR POLDOR20

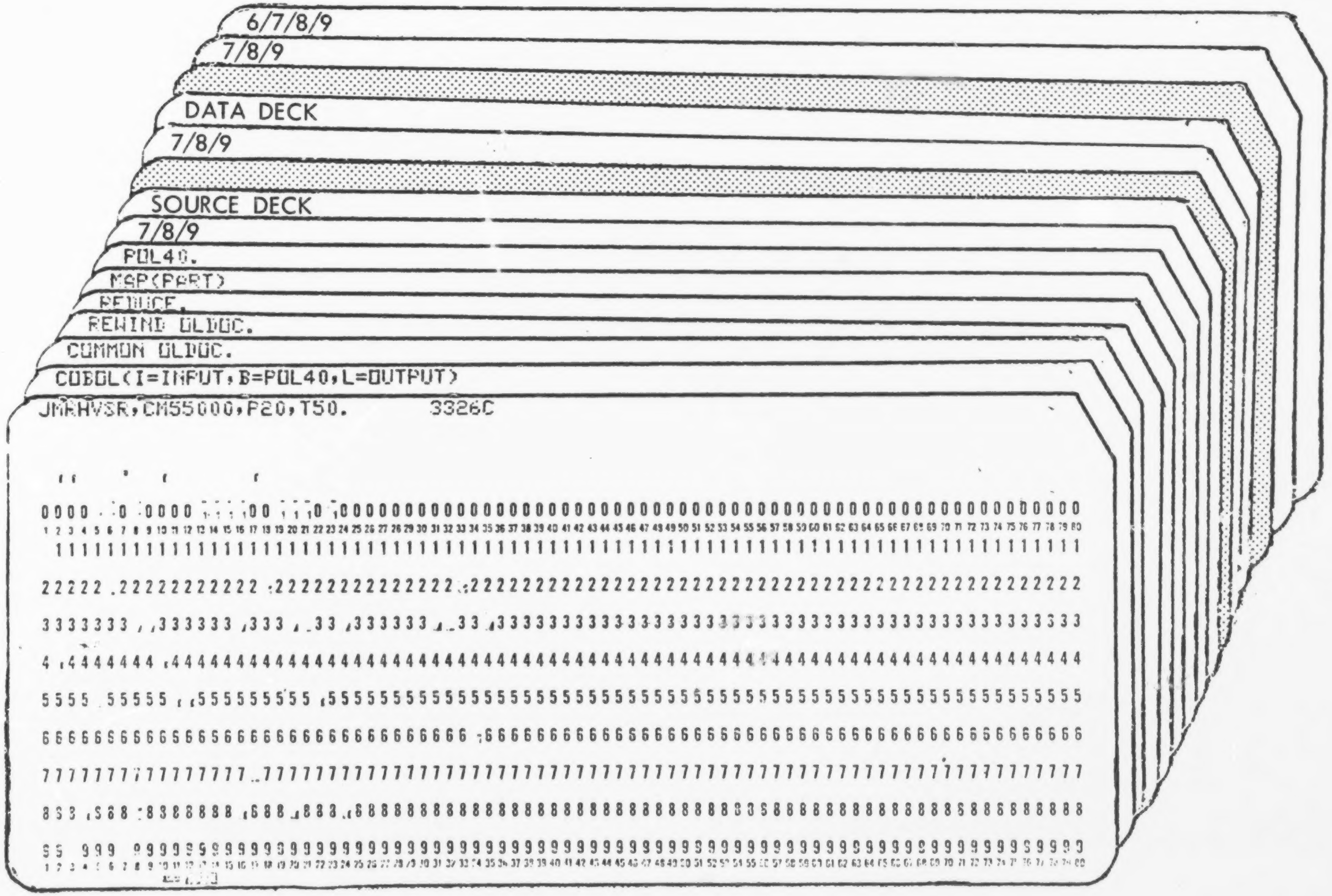


```
6/7/8/9
7/8/9

DATA DECK (SEARCH CRITERIA)
7/8/9

SOURCE DECK
7/8/9
POL20.
REDUCE.
MAP(PART)
LOAD(LGO)
REWIND DOCMT.
COMMON DOCMT.
COMMON POL20.
COBOL(I=INPUT,B=POL20,L=OUTPUT)
REWIND LGO.
FTN.
UMRHVSR,CM55000,P20,T1000.    3326C
```

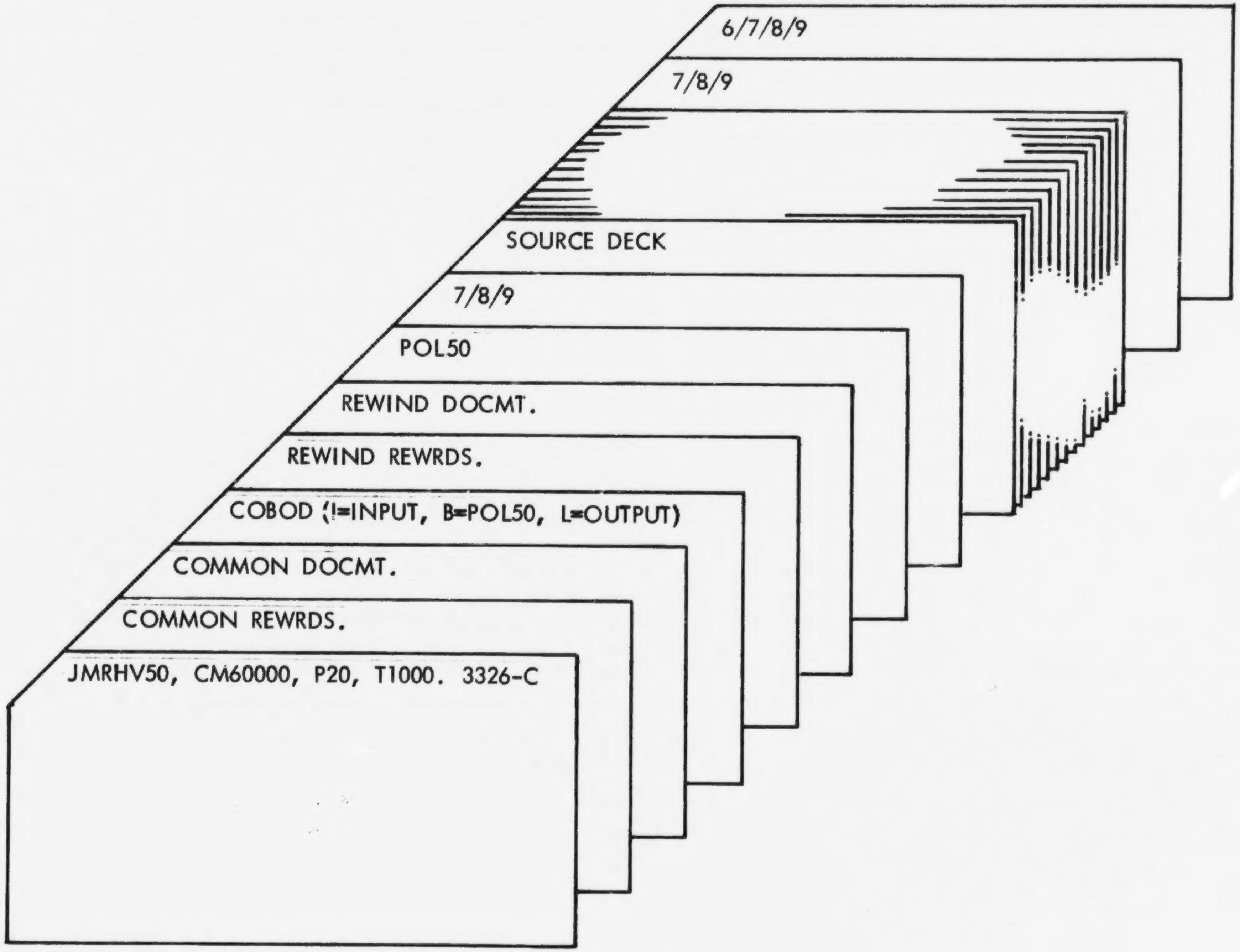
DECK SET-UP FOR POLDOR30


6/7/8/9
7/8/9
SOURCE DECK
7/8/9
POL30.
REDUCE.
REWIND DOCST.
COMMON DOCST.
COBOL(I=INPUT,B=POL30,L=OUTPUT)
UMRHV30,CM55000,T300,P20.   3326C

DECK SET-UP FOR POLDOR40



DECK SET-UP FOR POLDOR50



APPENDIX B

MASTER LIST

PARTICULATE POLLUTANT SOURCES

	Industrial Classification	S.I.C. No.
1.0	DOMESTIC AND COMMERCIAL HEATING PLANTS	0010
	Coal Fired	9000010
	Oil Fired	9010010
	Gas Fired	9020010
2.0	INDUSTRIAL HEATING PLANTS	0020
	Coal	9000020
	Oil	9010020
	Gas	9020020
	Lignite	9030020
	Wood and Bark	9040020
	Bagasse	9050020
	Fluid Coke	9060020
3.0	MINING	1000
	Iron	1010
	Copper	1020
	Lead	1030
	Zinc	1040
	Aluminum	1050

	Industrial Classification	S.I.C. No.
4.0	MINING AND QUARRYING OF NONMETALLIC MINERALS, EXCEPT FUELS	1400
5.0	FOOD AND KINDRED PRODUCTS	2000
	Meat Products	2010
	Meat Slaughtering Plants	2011
	Meat Processing Plants	2013
	Grain Mill Products	2040
	Flour and Other Grain Mill Products	2041
	Prepared Feeds for Animals and Fowl	2042
	Sugar	2060
	Cane Sugar, Except Refining Only	2061
	Cane Sugar Refining	2062
	Beet Sugar	2063
	Confectionery and Related Products	2070
	Candy and Other Confectionery Products	2071
	Chocolate and Cocoa Products	2072
	Miscellaneous Food Preparations and Kindred Products	2090
	Cotton Seed Oil Mills	2091
	Animal and Marine Fats and Oils	2094
	Coffee Roasting	2095
6.0	TEXTILE MILL PRODUCTS	2200
7.0	LUMBER AND WOOD PRODUCTS, EXCEPT FURNITURE	2400
	Wood Working	9002400

	Industrial Classification	S.I.C. No.
8.0	PAPER AND ALLIED PRODUCTS	2600
	Pulp Mills	2610
	Kraft	9002611
	Soda	9012611
	Lime Kiln	9022611
	Chemical	9032611
	Dissolver Tank Vents	9042611
	Digester	9052611
	Smelt Tank	9062611
	Recovery Furnace	9072611
	Evaporators	9082611
	Oxidation Towers	9092611
	Paper Mills, except Building Paper Mills	2620
	Paperboard Mills	2630
	Building Paper and Building Board Mills	2660
9.0	PRINTING AND PUBLISHING	2700
10.0	CHEMICAL AND ALLIED PRODUCTS	2800
	Industrial Inorganic and Organic Chemicals	2810
	Alkalies and Chlorine	2812
	Industrial Gases	2813
	Intermediate Coal Tar Products	2815

Industrial Classification	S.I.C. No.
Inorganic Pigments	2816
Organic Chemicals	2818
Inorganic Chemicals, N.E.C.	2819
Nitric Acid	9002819
Sulfuric Acid	9012819
Hydrochloric Acid	9022819
Phosphoric Acid	9032819
Plastic Materials & Synthetic Resins, Synthetic Rubber, Synthetic and Other Man-Made Fibers, except Glass	2820
Plastic Materials and Resins	2821
Synthetic Rubber	2822
Soap, Detergents, and Cleaning Preparations Perfumes, Cosmetics, and other Toilet Preparations	2840
Soap and Other Detergents	2841
Polish and Sanitation Goods	2842
Surface Active Agents	2843
Toilet Preparations	2844
Paints, Varnishes, Lacquers, Enamels and Allied Products	2850
Gum and Wood Chemicals	2860
Charcoal Manufacturing, Except Activated	9002861
Agricultural Chemicals	2870
Fertilizers	2871

	Industrial Classification	S.I.C. No.
	Phosphates	9002871
	Fertilizers, Mixing Only	2872
	Agricultural Chemicals, N.E.C.	2879
	Miscellaneous Chemical Products	2890
	Glue and Gelatin	2891
	Explosives	2892
	Printing Ink	2893
	Carbon Black	2895
	Furnace Black	9002895
	Channel Black	9012895
	Chemical Preparations	2899
11.0	PETROLEUM REFINING AND RELATED INDUSTRIES	2900
	Petroleum Refining	2910
	Catalytic Cracking	9002911
	Fluid Cokers	9012911
	Paving and Roofing Materials	2950
	Paving Mixtures and Blocks	2951
	Asphalt Dryers	9002951
	Asphaltic Felts and Castings	2952
	Miscellaneous Products of Petroleum and Coal	2990
	Lubricating Oils and Greases	2992
	Petroleum and Coal Products	2999

	Industrial Classification	S.I.C. No.
12.0	RUBBER AND MISCELLANEOUS PLASTICS PRODUCTS	3000
	Tires and Inner Tubes	3010
	Rubber Footwear	3020
	Fabricated Rubber Products, N.E.C.	3060
	Miscellaneous Plastic Products	3070
13.0	LEATHER AND LEATHER PRODUCTS	3100
	Leather Tanning and Finishing	3110
14.0	STONE, CLAY, GLASS & CONCRETE PRODUCTS	3200
	Flat Glass	3210
	Glass and Glassware, Pressed or Blown	3220
	Glass Containers	3221
	Pressed & Blown Glass, N.E.C.	3229
	Fiberglass	
	Frit Manufacture	
	Perlite Manufacture	
	Rock Wool Manufacture	
	Cupula	
	Reverb. Furnace	
	Blow Chamber	
	Curing Overn	
	Cooler	

Industrial Classification	S.I.C. No.
Cement, Hydraulic	3240
Kiln	9003241
Cooling	9013241
Grinding	9023241
Silo	9033241
Bagging	9043241
Bulk Loading	9053241
Structural Clay Products	3250
Brick and Structural Tile	3251
Clay Refractories	3255
Structural Clay Products, N.E.C.	3259
Concrete, Gypsum & Plaster Products	3270
Concrete Block and Brick	3271
Other Concrete Products	3272
Ready Mixed Concrete	3273
Lime	3274
Gypsum Products	3275
Cut Stone and Stone Products	3280
Abrasive, Asbestos, and Miscellaneous Nonmetalic Mineral Products	3290
Abrasive Products	3291
Asbestos Products	3292
Gaskets and Insulation	3293

Industrial Classification	S.I.C. No.
Minerals, Ground or Treated	3295
Nonclay Refractories	3297
15.0 PRIMARY METAL INDUSTRIES	3300
Blast Furnaces, Steel Works, and Rolling and Finishing Mills	3310
Blast Furnaces	9003312
Open Hearth	9013312
Basic Oxygen Furnace	9023312
Sintering	9033312
Coke Ovens	9043312
Ore Roasters	9053312
Pyrites Roaster	9063312
Taconite	9073312
Scarfing	9083312
Electric Furnace	9093312
Electrometallurgical Products	3313
Steel Wire Drawing	3315
Cold Finishing of Steel Shapes	3316
Steel Pipe and Tube	3317
Iron and Steel Foundries	3320
Cupola	9003320
Shake Out	9013320

Industrial Classification	S.I.C. No.
Grinding	9023320
Shot Blasting	9033320
Sand Handling	9043320
Electric Induction Furnace	9053320
Electric Arc Furnace	9063320
Primary Smelting and Refining of Nonferrous Metals	3330
Primary Smelting and Refining of Copper	3331
Copper Roaster	9003331
Copper Reverb.	9013331
Copper Converter	9023331
Primary Smelting and Refining of Lead	3332
Lead Furnace	9003332
Primary Smelting and Refining of Zinc	3333
Zinc Roaster	9003333
Zinc Smelter	9013333
Primary Production of Aluminum	3334
Primary Smelting and Refining of Non-ferous Metals, N.E.C.	3339
Elemental Phos.	9003339
Limenite	9013339
Titanium	9023339
Molybdenum	9033339

	Industrial Classification	S.I.C. No.
	Secondary Smelting and Refining of Nonferrous Metals	3340
	Nonferrous Foundaries	3360
	Aluminum Castings	3361
	Brass, Bronze, Copper Castings	3362
	Non-ferrous Castings, N.E.C.	3369
	Miscellaneous Primary Metal Products	3390
	Iron and Steel Forgings	3391
	Primary Metal Industries, N.E.C.	3399
16.0	FABRICATED METAL PRODUCTS	3400
17.0	MACHINERY, EXCEPT ELECTRICAL	3500
18.0	ELECTRICAL MACHINERY	3600
19.0	INSTRUMENTS	3800
20.0	ELECTRIC, GAS AND SANITARY SERVICES	4900
	Electric Companies & Systems	4910
	Coal	9004911
	Oil	9014911
	Gas	9024911
	Lignite	9034911
	Sanitary Services	4950
	Incinerators	4953
	Apartment House	9004953

Industrial Classification	S.I.C. No.
Commercial and Industrial	9014953
Municipal	9024953
Auto Body and Scrap Wire	9034953
Sewage Sludge (Incinerators)	9044953
Waster Liquid (Incinerators)	9054953
Steam Supply	4960

APPENDIX C

COMPUTATION OF EMISSIONS BASED ON AN AVERAGE ANNUAL COLLECTION EFFICIENCY

(See Section 5 for background information.)

There are many factors that result in lower collection efficiency, on an annual basis, as discussed in Section 5. It is difficult, however, to assess what this annual efficiency might be for any industry. Taking into account that operating problems, downtime, and capture efficiency of hooding systems, etc., can all seriously decrease collection efficiency, it has been assumed that the annual collection efficiency, for any industry, could approach 90% of the efficiency figures determined in Section 5, and shown in Table 4.1-1.

This is similar to the operating factor that is used to represent decreased production and downtime in the design of process plants. Using this value of 90% and applying it to the efficiencies shown in Table 4.1-1, the emissions for each industrial source have been recomputed as shown in Table C-1.

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TABLE C-1

COMPARISON OF PARTICULATE EMISSIONS

Source	Emissions, per Table 4.1-1 (tons/yr)	Emissions, assuming that annual collection efficiency is 90% of efficiency shown in Table 4.1-1 (tons/yr)
1. Fuel Combustion	5,946,000	8,624,000
2. Crushed Stone, Sand & Gravel	4,600,000	4,714,000
3. Agricultural Operations	1,768,000	1,843,000
4. Iron and Steel	1,344,000	2,183,000
5. Cement	931,000	1,629,000
6. Forest Products	666,000	1,002,000
7. Lime	573,000	708,000
8. Clay	468,000	542,000
9. Primary Nonferrous	464,000	654,000
10. Fertilizer and Phosphate Rock	337,000	337,000
11. Asphalt	218,000	721,000
12. Ferroalloy	160,000	180,000
13. Iron Foundries	143,000	148,000
14. Secondary Nonferrous	127,000	134,000
15. Coal Cleaning	94,000	94,000
16. Carbon Black	93,000	93,000
17. Petroleum	45,000	45,000
18. Acids	16,000	28,000
Total	17,993,000	23,679,000